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OXYGEN STORAGE ON ZEOLITES

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19. ABSTRACT

In an effort to eliminate hazards associated with high pressure and liquid oxygen reserve systems, the United States Air Force has supported studies at the University of Texas to determine the feasibility of using zeolite filled cylinders for oxygen storage. Because of the adsorptive capacity of the zeolite, more oxygen can be contained in a zeolite filled cylinder than in an unpacked cylinder, depending on the pressure.

However, this study has revealed that *differences* in adsorptive capacity between charge and exhaust pressures determine the *deliverable* amount of gas in a bed. Using this criterion (instead of merely comparing isotherm capacities to unpacked cylinder capacities), the advantage of zeolite filled cylinders over unpacked cylinders is diminished.

Parameters have been measured to allow calculation of estimated bed size for a 200 liter (NPT) reserve oxygen system. Assuming an exhaust pressure of 8.82 psia (0.6 atm), the required size of the system for an unpacked cylinder operating at OBOGS pressure (40 psig) is approximately 64.2 liters. The same system filled with zeolite is 16.8 liters (zeolite mass is 13.2kg). While the improvement using the zeolite is impressive, the cylinder size does not compare

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19. ABSTRACT (Continued)

favorably with the 1 liter size of an unpacked cylinder operating at 3000 psig. Thus, if space is a serious limitation on an aircraft, the zeolite filled reserve system probably cannot be used at OBOGS pressure.

If a compressor is available, system size can be further reduced, at the expense of weight and reliability (because of the compressor). At 200 psig, the volume of a zeolite packed reserve system (for 200 liter NPT oxygen) would be 5.1 liters; at 350 psig, the volume would be 3.7 liters; at 500 psig, the volume would be 3.0 liters. The corresponding masses would be 4.1, 2.9, and 2.4 kg. The corresponding unpacked cylinder volumes would be 14.3, 8.3, and 5.8 liters. Note that the ratio of volumes (unpacked cylinder:packed cylinder) decreases with pressure; this indicates that the advantage of using cylinders packed with zeolite is less at higher pressures. (AW)

In conclusion, it is certainly possible to decrease reserve system volume by using zeolite packed beds instead of unpacked cylinders. Furthermore, the zeolite system (with an on-board compressor) can be refilled in flight or on the ground without external oxygen supplies. However, the zeolite filled beds may not fit in existing aircraft because of size limitations, and an in-flight refill capacity of an emergency reserve system may be of dubious utility. Zeolite filled reserve systems can only be attractive if the logical problems of liquid oxygen and higher pressure oxygen systems dominate the size and weight penalties of a zeolite system.

TABLE OF CONTENTS

List of Figures

List of Tables

OXYGEN STORAGE ON ZEOLITES

INTRODUCTION

The United States Air Force (USAF) has expressed an interest in the possibility of using packed beds of zeolites for oxygen storage in reserve systems. These packed beds can contain more gas than similarly sized unpacked beds due to the adsorptive capacity of the zeolite. However, the packed bed system will contain more mass per unit volume of bed.

The primary uncertainties in considering zeolite packed beds lie in determining how much of the adsorbed gas will be deliverable when venting. To quantify the deliverable amount of gas from such a system, experiments have been done at the University of Texas.

Since the inception of this work, Union Carbide has stopped selling its zeolite 13X (also designated MG3) under that name. An alternative product has been tested in our laboratories: Union Carbide OxySieve-5. In outward appearance, this material closely resembles the older zeolite 13X product. Thus, in circumstances where data were unavailable for OxySieve-5, the corresponding zeolite 13X data were used. The other zeolite considered in this work was Union Carbide 5AMG.

THEORY

Basically, the zeolitic reserve system is an equilibrium system. As noted in the last report (APPENDIX A), its capacity is the adsorptive capacity of the bed packing plus the amount of gas in the interstices of the bed. The deliverable amount of gas is the difference in bed capacity between the operating (charged) pressure and the venting pressure.

The last report discussed the application of Ruthven's statistical thermodynamic isotherm to the zeolite 5A system (1). Supplementary data were obtained from Miller's thesis (2). The deliverable amount of gas from a packed bed can be expressed as:

$$n_{net} = \frac{\varepsilon}{\rho_{Bed}}\left(n_{op} - n_{vent}\right) + \left(a_{op} - a_{vent}\right) \qquad (1)$$

where n_{op} is the amount of oxygen in the voids at operating pressure (g/l), n_{vent} is the amount of oxygen at venting pressure (g/l), ε is the void fraction of the bed, ρ_{Bed} is the bulk density of the bed (kg/l), a_{op} and a_{vent} are the adsorbed amounts of oxygen at operating and venting pressures (g/kg zeolite), and n_{net} is the amount of oxygen deliverable (g/kg zeolite). Isotherm information is required to find both a_{op} and a_{vent}, values for ε and ρ_{Bed} must be known, and compressibility charts should be consulted to calculate the deliverable capacity of the bed.

Equation (1) is interesting because it emphasizes the fact that *differences* in adsorptive capacity are most important to the performance of the zeolite filled reserve system. Figure 1 shows how a zeolite with a lower capacity (R) can outperform a higher capacity material (Q), depending on operating conditions. If the operating pressure is P_3 and the venting pressure is P_2, then it is clear that R is better than Q because the difference ($n_{R,3}$ - $n_{R,1}$) is greater than the difference ($n_{Q,3}$ - $n_{Q,1}$). In fact, even if the venting pressure is P_1, material R is superior. The total capacity of an adsorbent is not the most important attribute of a candidate material for a reserve system. A good material will be one that maximizes the difference of adsorbed amounts over the pressure range of interest; therefore, operation should be in the steepest part of the isotherm. The average slope over the pressure range may be a reasonable discriminator among materials.

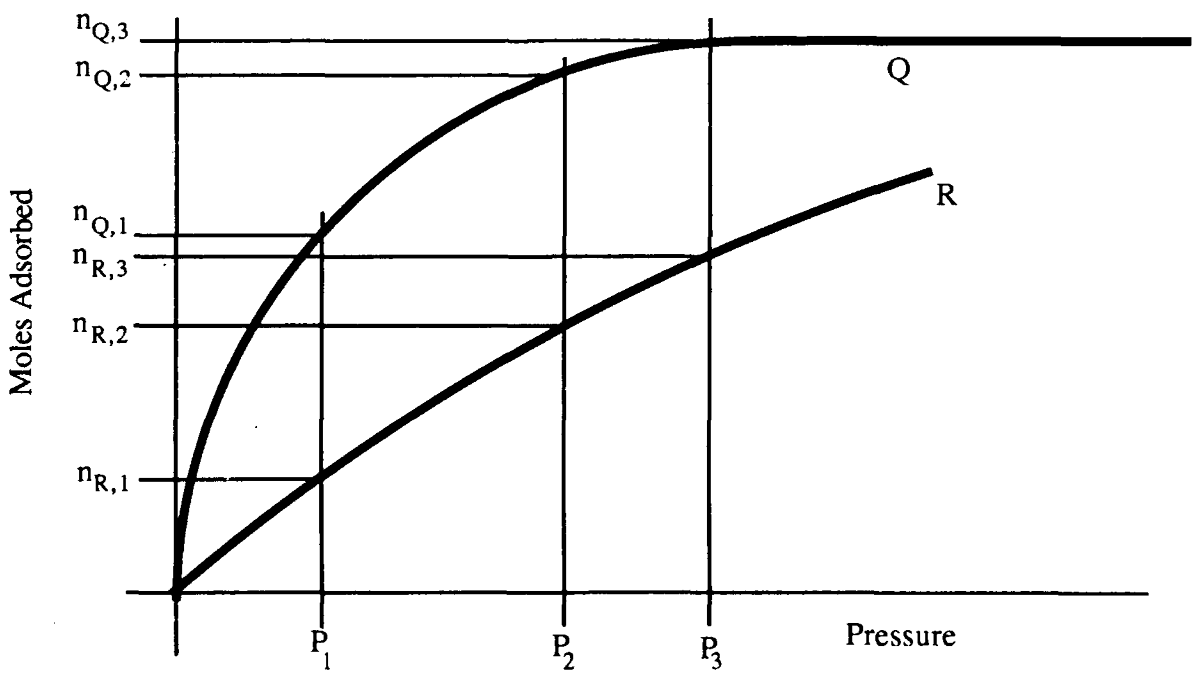


Figure 1. Deliverable oxygen example.

EXPERIMENTAL

The experimental equipment was constructed as in Figure 2. The bed used was 2.54-cm (1 in.) O.D. by 0.0889-cm (0.035 in.) wall thickness. Bed length was 67 cm (26.8 in.) (of which approximately 63.5 cm (25.4 in.) were packed with zeolite). Two pressure gauges were used: a Matheson 0-100 psig gauge (P/N 63-3212) and an AirCo 76.2-cm (30 in.) Hg vacuum-200 psig gauge (P/N 054-30052). Both gauges were calibrated immediately prior to the experiments. The AirCo gauge was used in most experiments because of the limited pressure range of the Matheson gauge.

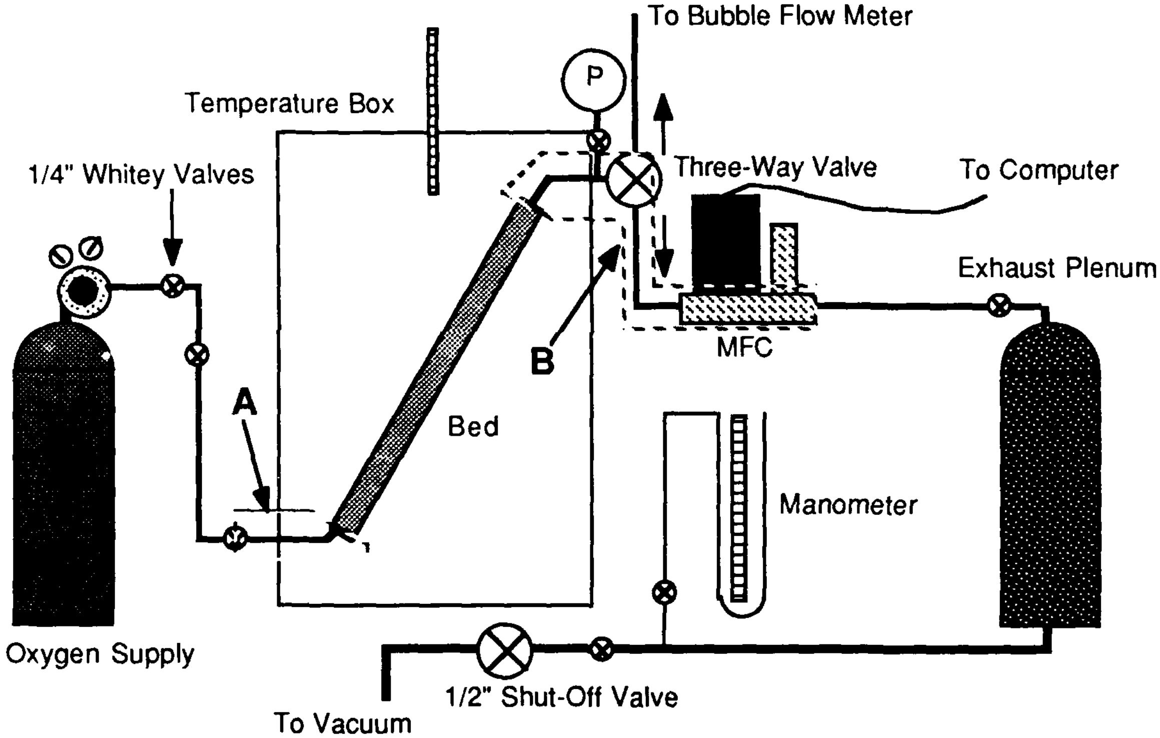


Figure 2. Experimental equipment.

The three-way valve, after the bed, was used for venting and during activation. Its normal position directed flow to the mass flow controller (MFC).

A Sierra Instruments MFC (Series 840) calibrated for 0-1 standard liters per minute (SLPM) helium flow was used. This MFC uses the heat capacity of the gas stream for measurement of the mass flow. Using standard industry calibration tables, the corresponding range for oxygen is 0-688 standard cubic centimeters per minute (SCCM). This value was used to convert MFC output from helium to oxygen. The MFC was connected to the exhaust plenum by a 0.635-cm (1/4 in.) stainless tube.

The exhaust plenum was a large high pressure gas cylinder (T-type) with a 3/4 in. NPT hole tapped in the bottom to allow for connection to vacuum. The plenum was connected through a standard Whitey 0.635-cm (1/4 in.) valve (for controlling vacuum pressure) and a 1.27-cm (1/2 in.) shut-off valve to the vacuum pump. A pressure tap connected the line from the plenum to the vacuum pump to a manometer for measurement of the vacuum.

The temperature box was a Blue-M Stabil-Therm oven, with a range from room temperature to approximately 60 °C (140 °F). The temperature in the box was originally measured using a thermometer in the bottom of the box, but apparent temperature gradients in the box necessitated a different placement. Therefore, the thermometer was placed through a hole in the top of the box. This placement gave better agreement with the temperature settings on the box controller as well as better agreement with an auxiliary thermocouple mounted on the outside of the bed (in the temperature box).

Activation of the zeolites was done *in situ* at 350 °C (662 °F) with approximately 30 SCCM helium flow at atmospheric pressure. Heating tapes were wrapped around the bed and covered by Manville Thermo-12 insulation. The bed was activated for a minimum of 24 hours. Because activation was done in the bed, no material transfer was required; therefore, the zeolite is considered to be highly activated.

In a typical run, temperature was allowed to stabilize overnight. Then (except in the atmospheric exhaust pressure case), exhaust pressure was pulled on the bed for approximately 15 minutes (initial experiments indicated that this helped reproducibility). Next, the bed was pressurized with oxygen and allowed to stabilize for a given amount of time (settling time). Finally, the MFC was opened and the flow was recorded versus time. This information was trapezoidally integrated to give the total mass delivered by the bed during the blowdown.

Program O2STORE was written to control the experiment and acquire data from the opening of the MFC onward. The program is included as Appendix B; typical output is in Appendix C. Scientific Solutions LabMaster and DADIO boards were used in an IBM-PCXT for data acquisition and MFC control.

Unpacked volume in the experimental system (sections A and B in Fig. 2) was found from the dimensions of fittings and tubing lengths. Water displacement, which would have been preferred, was not done due to difficulties in drying the system as well as the fact that some fittings are permanently mounted through the temperature box. These fittings could not, therefore, be rotated to remove trapped air bubbles (if water displacement were attempted). Furthermore, water displacement could not be used to find dead space at the ends of the packed bed because of its effect on the molecular sieve. The total unpacked volume of the pressurized part of the system was 29.68 cm^3 (1.811 $in.^3$).

Parameters were varied as shown in Table 1, and represent equipment limits.

TABLE 1. PARAMETER SPACE

	Lower	Upper
Temperature (°C (°F))	25 (77)	60 (140)
Bed Pressure (psig)	20	130
Exhaust Pressure (inch Hg vacuum)	24	0

An experimental design was constructed to allow determination of a quadratic response surface in all variables and is shown in Tables 2 and 3 (3,4).

TABLE 2. EXPERIMENTAL DESIGN (SYMBOLIC)

Run #	Bed pressure	Temperature	Exhaust pressure
1	0	$-\alpha$	0
2	+	-	-
3	-	-	+
4	0	0	$+\alpha$
5	$+\alpha$	0	0
6	$-\alpha$	0	0
7	0	0	$-\alpha$
8	+	+	+
9	-	+	-
10	0	$+\alpha$	0

TABLE 3. EXPERIMENTAL DESIGN (NUMERIC)

Run #	Bed Pressure (psig)	Temp. (°C(°F))	Ex. Pressure (in. Hg vac)
1	80	25 (77)	12
2	110	34 (93.2)	18
3	50	34 (93.2)	6
4	80	42.5 (113.9)	0
5	132	42.5 (113.9)	12
6	20	42.5 (113.9)	12
7	80	42.5 (113.9)	24
8	110	51 (123.8)	6
9	50	51 (123.8)	18
10	80	60 (140)	12

RESULTS

Tabulated results are in Appendix D.

Figure 3 shows runs done to test reproducibility. These runs are all for a 4-min settling time. Over these runs, the variation in total mass delivered in the run was less than ±0.5% (from the average). The graphs plot the raw data, flow versus time.

Figures 4 and 5 compare settling times for oxygen on zeolites 5A and OxySieve-5, respectively. The flow versus time plots are again shown. In Figure 4, the settling times are varied from 10 min to approximately 13.5 h (specifically, runs R5O2, R6O2, R7O2, R8O2, R9O2, and R10O2 have settling times of 10, 26, 40, 66, 152, and 807 min , respectively). The difference between the total mass delivered between runs R8O2 and R10O2 was less than 0.5%. Therefore, a 1 h settling time was chosen for the remaining zeolite 5A experiments.

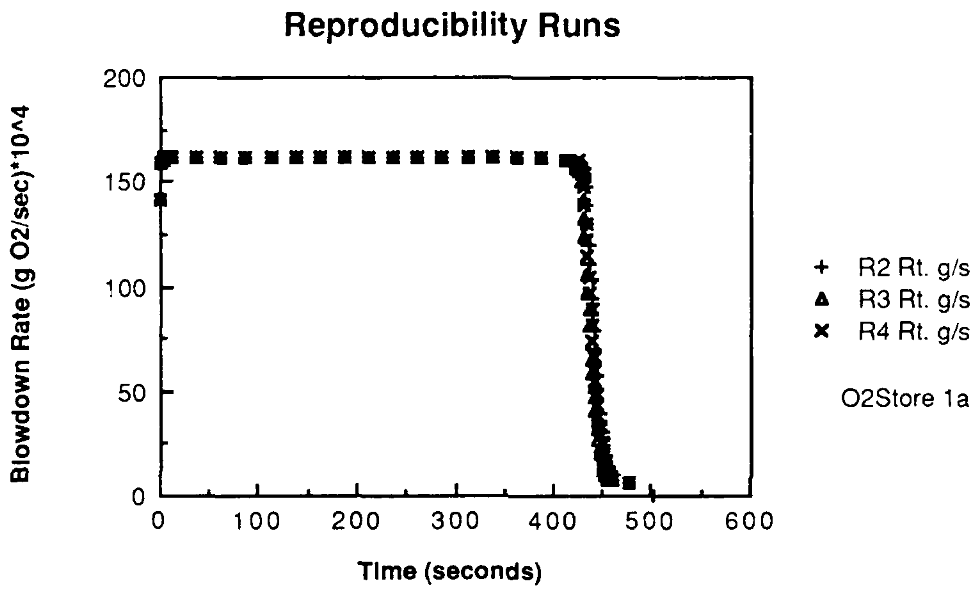
Figure 5 shows a bit more variability than in Figure 4. These runs are for OxySieve-5 and range from 10 min to 1 h (R22O2, R23O2, and R24O2 have settling times of 10, 30, and 62 min , respectively). Because some question arose as to the temperature distribution in the temperature box, an extra thermocouple was fitted to the bed itself before the OxySieve-5 experiments. This change indicated that a temperature rise of 2-3 °C (3.6-5.4 °F) could be associated with pressurization of the bed. This temperature rise explains the reduced mass delivered by the bed for short settling times (the temperature rise causes bed capacity to be slightly lowered). Furthermore, the extra thermocouple indicated that the bed temperature returned to the box temperature within an hour, which is why the 13.5 h and 1 h zeolite 5A runs varied only to within the reproducibility error (the temperature was essentially the same throughout the bed for any settling time greater than 1 h).

I concluded that the 1 h settling time would be adequate for the OxySieve-5 tests on the basis of the thermocouple readings as well as the fact that the variability among the runs in Figure 5 was less than 1.0% from average.

The data from the ten valid runs done for each of the zeolites were then substituted into an expression for a quadratic surface. A linear system of equations for the parameters results. The parameter values are presented in Table 4 for the equation:

$$n_{net} = A + B*P + C*T + D*Q + E*P^2 + F*T^2 + G*Q^2 + H*P*T + I*P*Q + J*T*Q \qquad (2)$$

with P=bed pressure (atm); T=temperature (Kelvin); Q=exhaust pressure (atm); n_{net}=deliverable oxygen (gm O2/kg zeolite); and A through J are the parameters. Because this surface passes through all the data points, it is considered the best interpolant of the data.



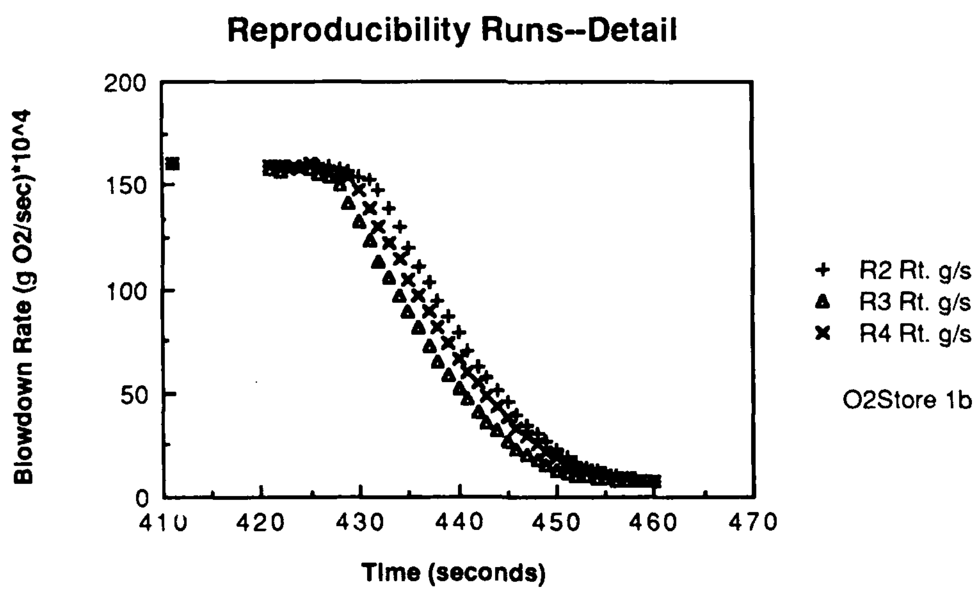


Figure 3. Reproducibility examples.

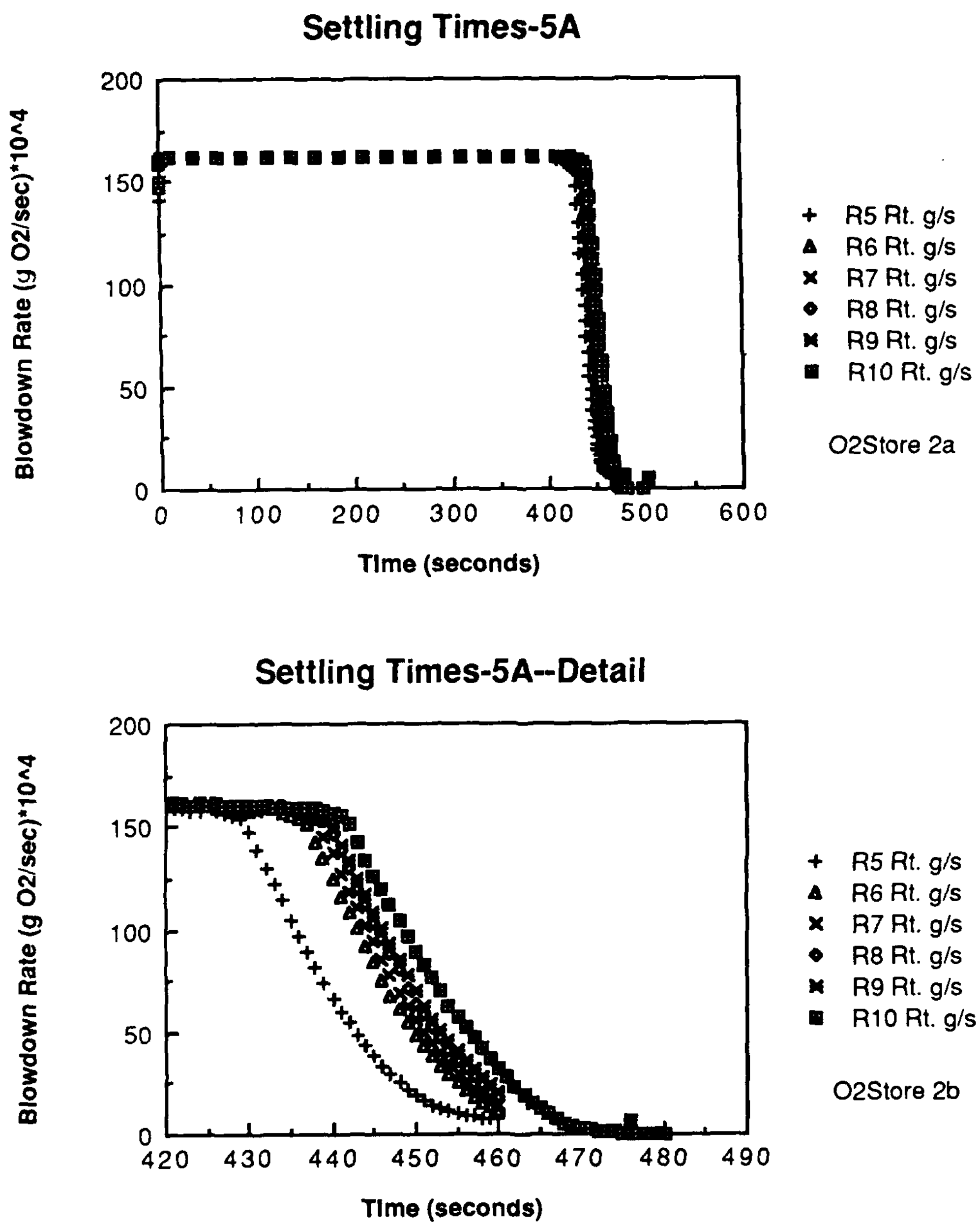
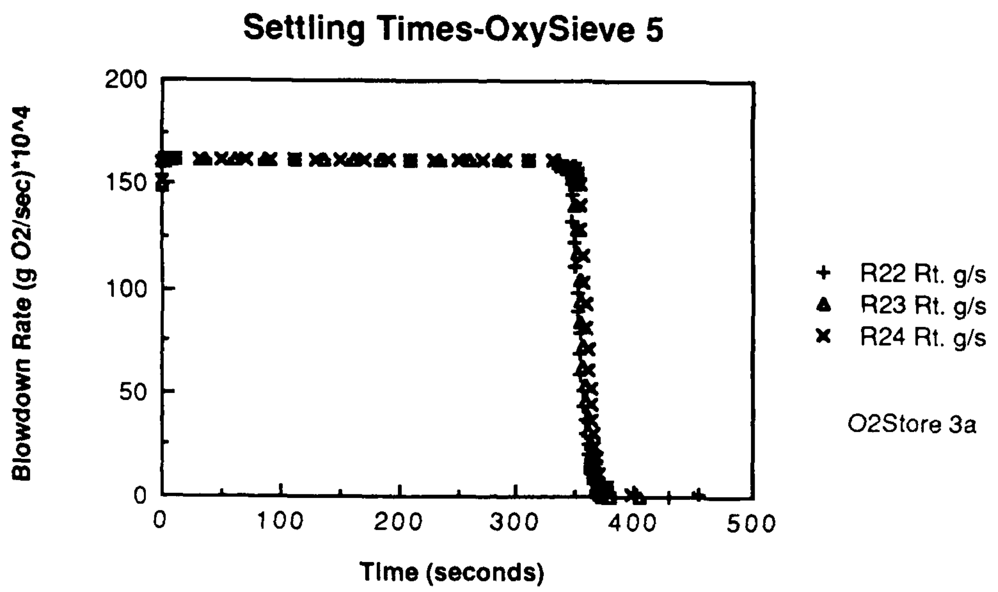


Figure 4. Settling time runs-zeolite 5A.



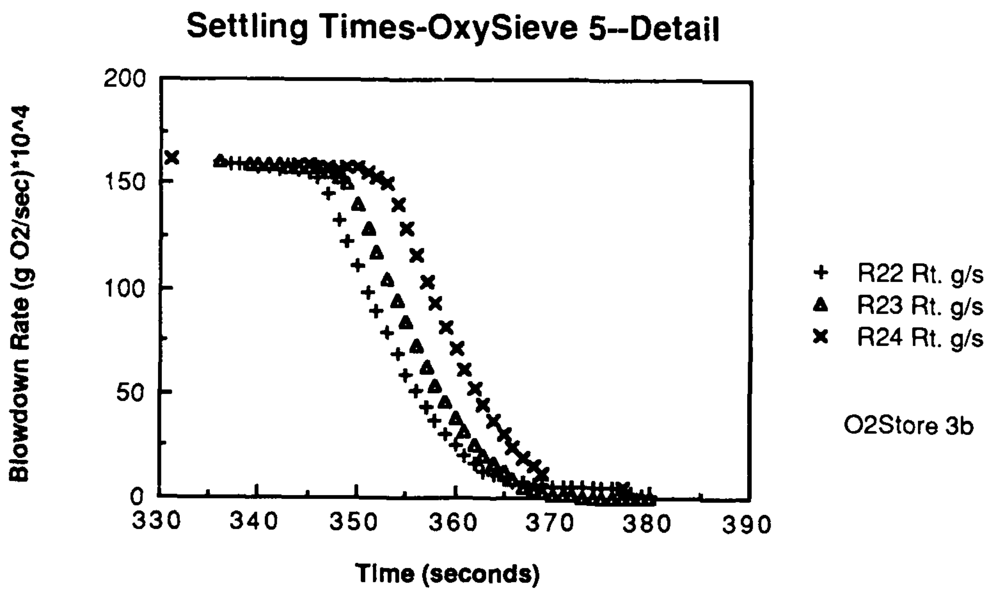


Figure 5. Settling time runs-OxySieve-5.

TABLE 4. PARAMETER VALUES--QUADRATIC SURFACE

(See Equation (2))

Parameter	Zeolite 5A	OxySieve-5
A	4.0666E+2	3.6967E+2
B	1.3258E+1	1.4319E+1
C	-2.2987E+0	-2.2270E+0
D	-7.8444E+1	-4.5342E+1
E	-5.4150E-2	-2.6480E-2
F	3.2347E-3	3.3705E-3
G	2.2653E+0	2.0524E+0
H	-2.7460E-2	-3.3032E-2
I	8.6892E-3	2.0487E-1
J	2.2064E-1	1.1726E-1

The quadratic surface is plotted in Figure 6 for zeolite 5A at 298 K. A contour plot for this surface is plotted for zeolite 5A at 298 K in Figure 7. The surface for OxySieve-5 is in Figure 8 and the accompanying contour plot is included as Figure 9. Surfaces at other temperatures have similar shapes, although the values of n_{net} are somewhat less (this axis is labeled GMO2 in the figures).

Because the surfaces are so flat, linear multiple regression was applied to the data in an attempt to reduce the number of parameters. Parameters found in multiple linear regression are A through D in Equation (2) and are presented in Table 5. The surfaces and contours for the multiple regression model at 298 K are presented in Figures 10-13, on the same axes as Figures 6-9. Over the range of bed and exhaust pressures investigated, the surfaces match quite well.

TABLE 5. PARAMETER VALUES--MULTIPLE REGRESSION SURFACE

(See Equation (2))

Parameter	Zeolite 5A	OxySieve-5
A	101.2	77.366
B	3.849	3.703
C	-0.304	-0.237
D	-5.836	-5.32

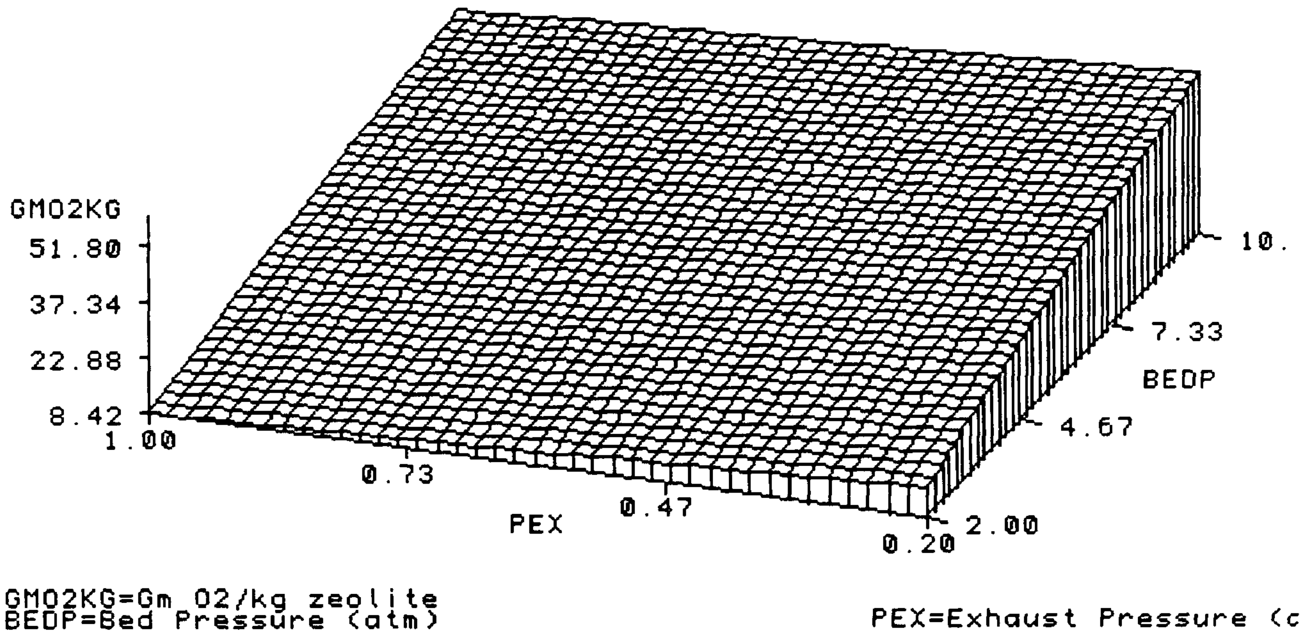


Figure 6. Zeolite 5A quadratic surface, T=298 K.

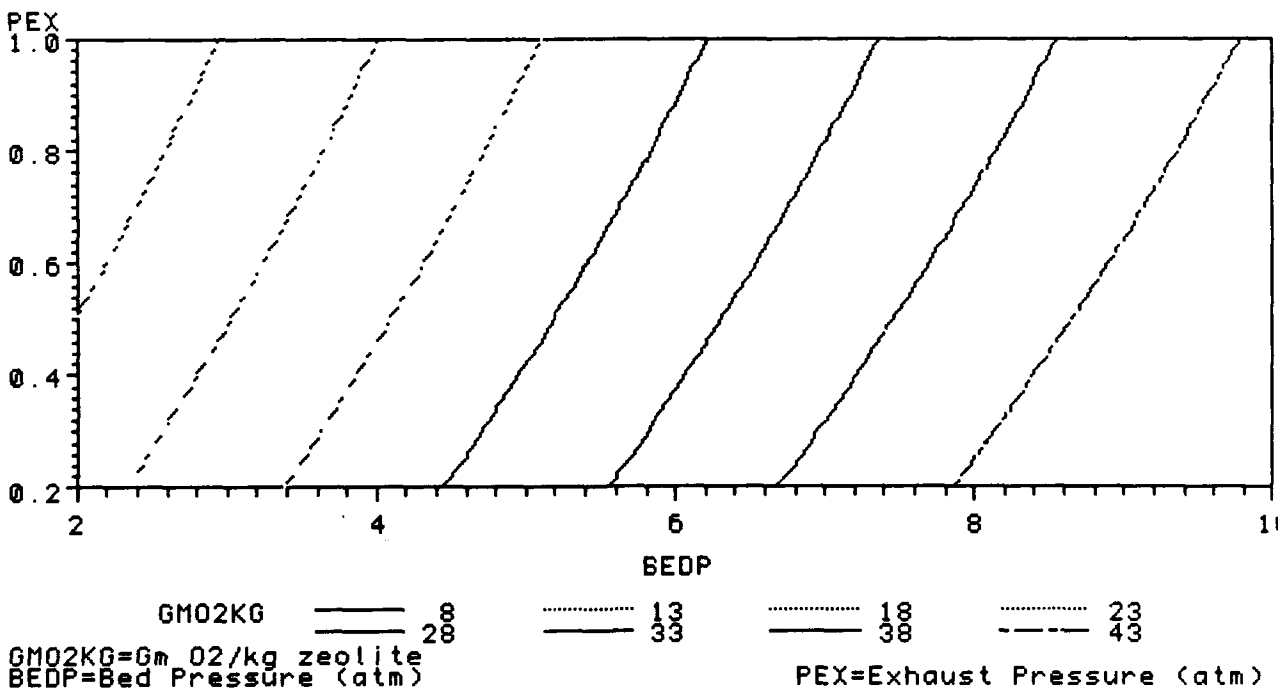


Figure 7. Zeolite 5A quadratic surface, T=298 K--contours.

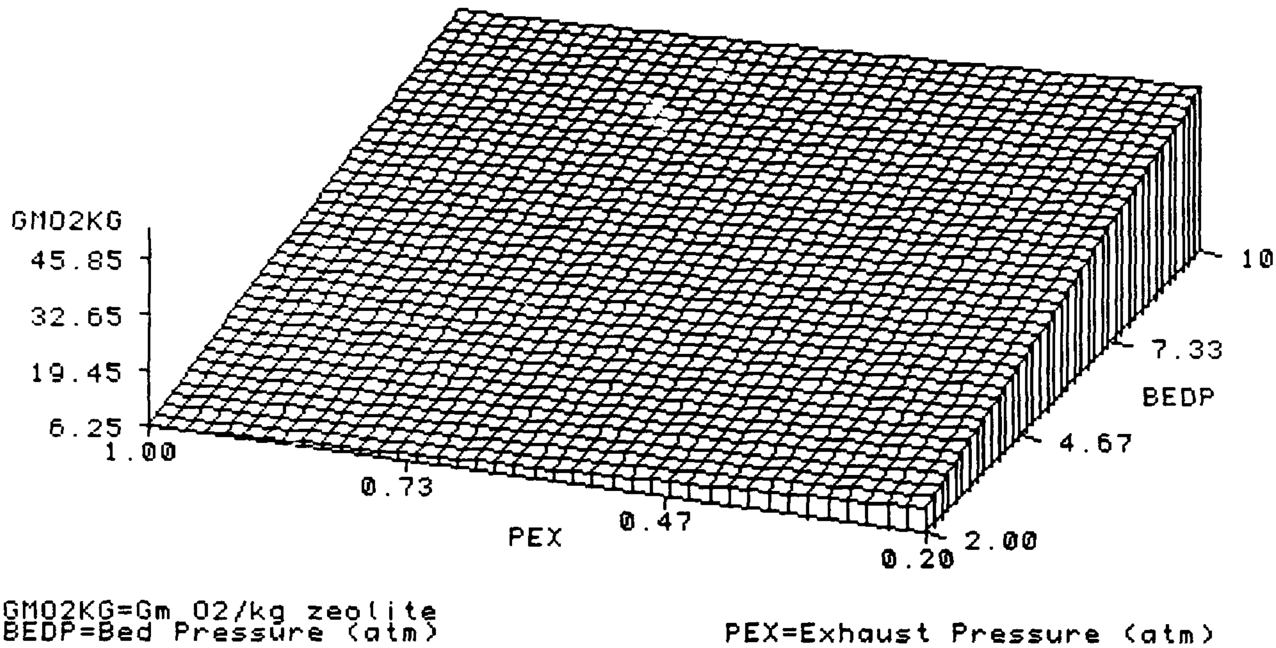


Figure 8. OxySieve-5 quadratic surface, T=298 K.

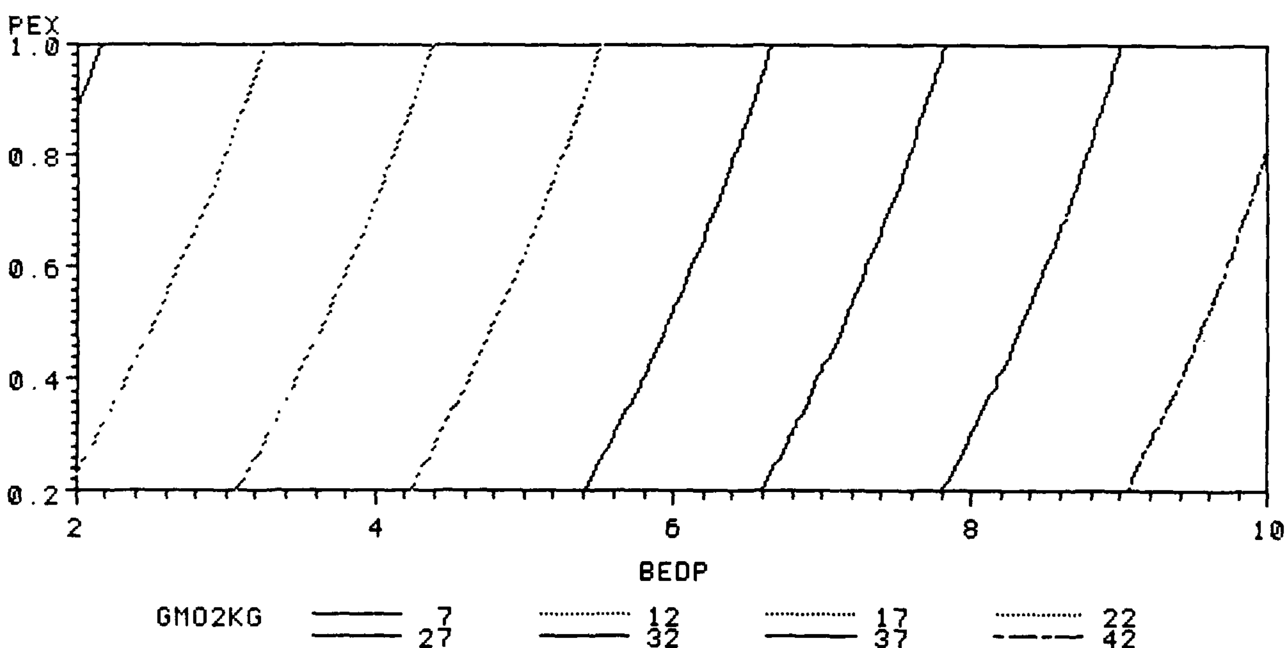


Figure 9. OxySieve-5 quadratic surface, T=298 K--contours .

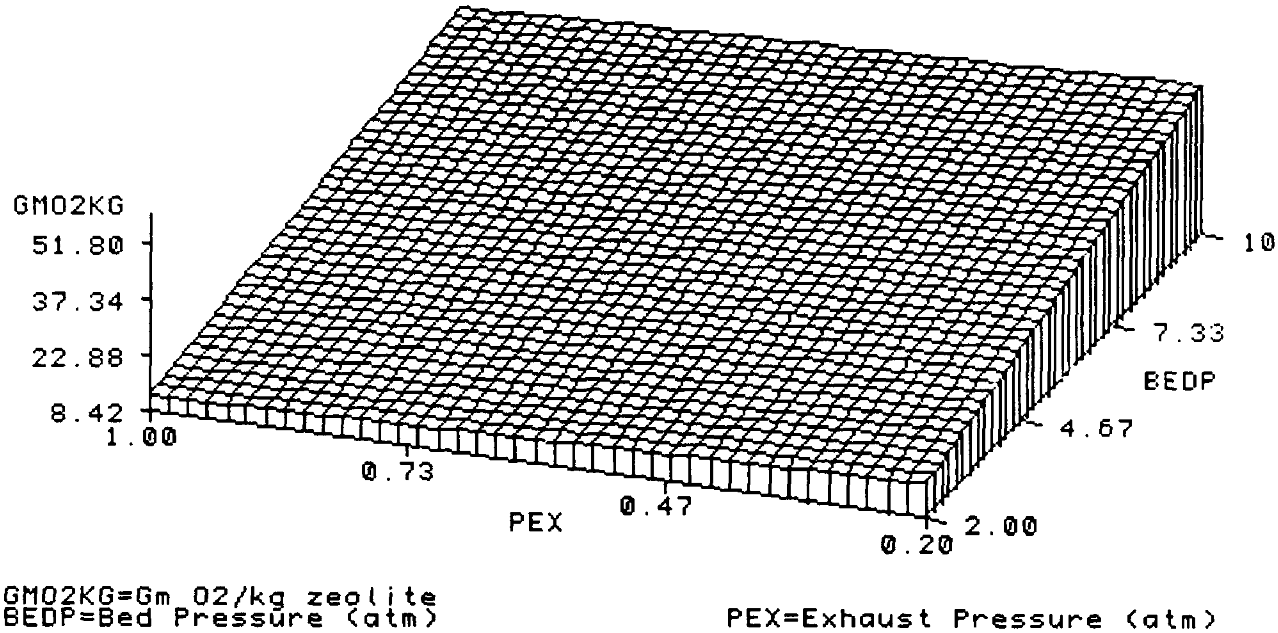


Figure 10. Zeolite 5A multiple regression surface, T=298 K.

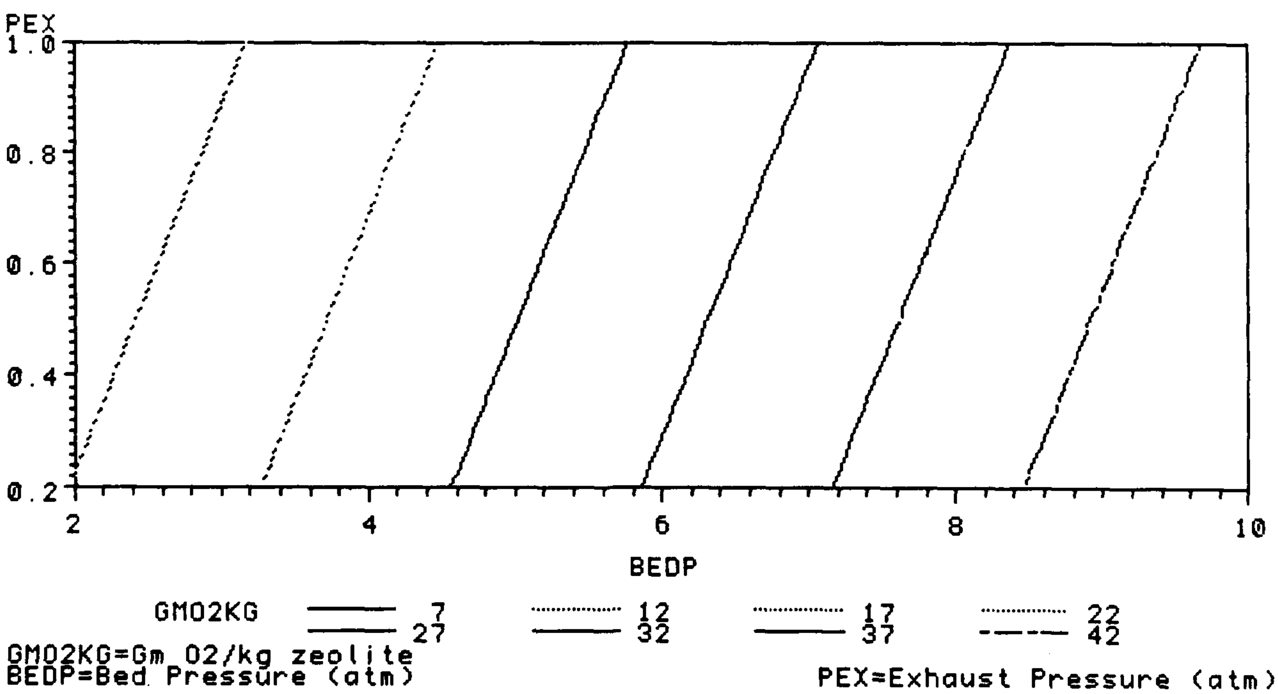


Figure 11. Zeolite 5A multiple regression surface, T=298 K--contours.

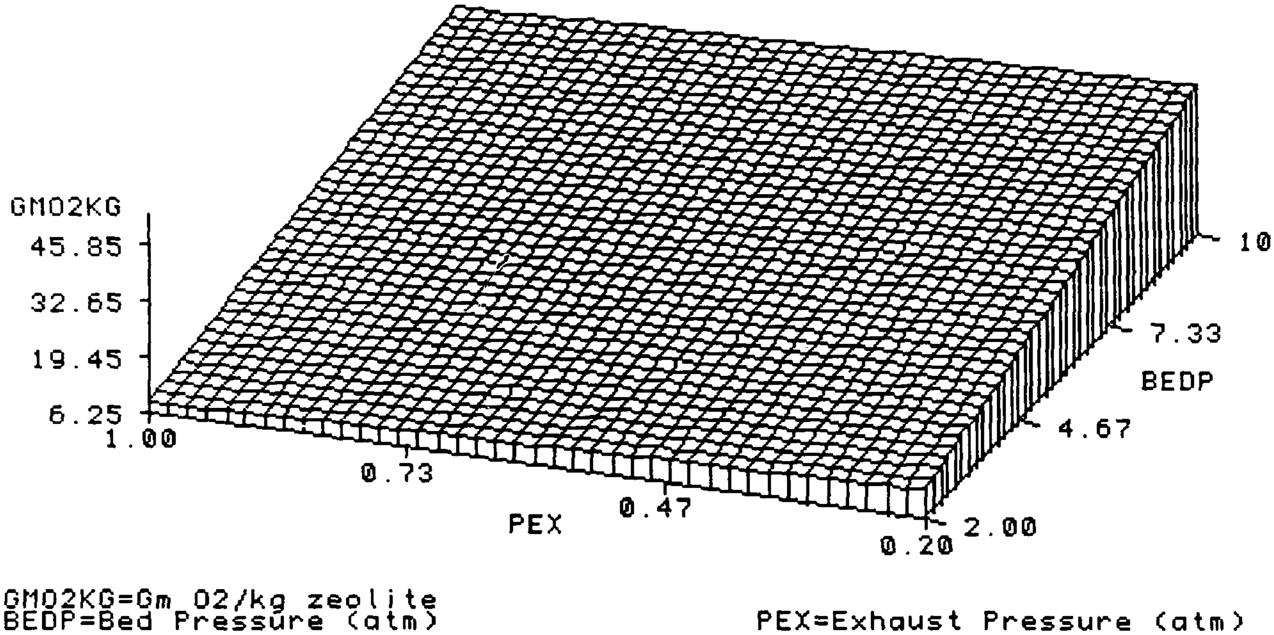


Figure 12. OxySieve-5 multiple regression surface, T=298 K.

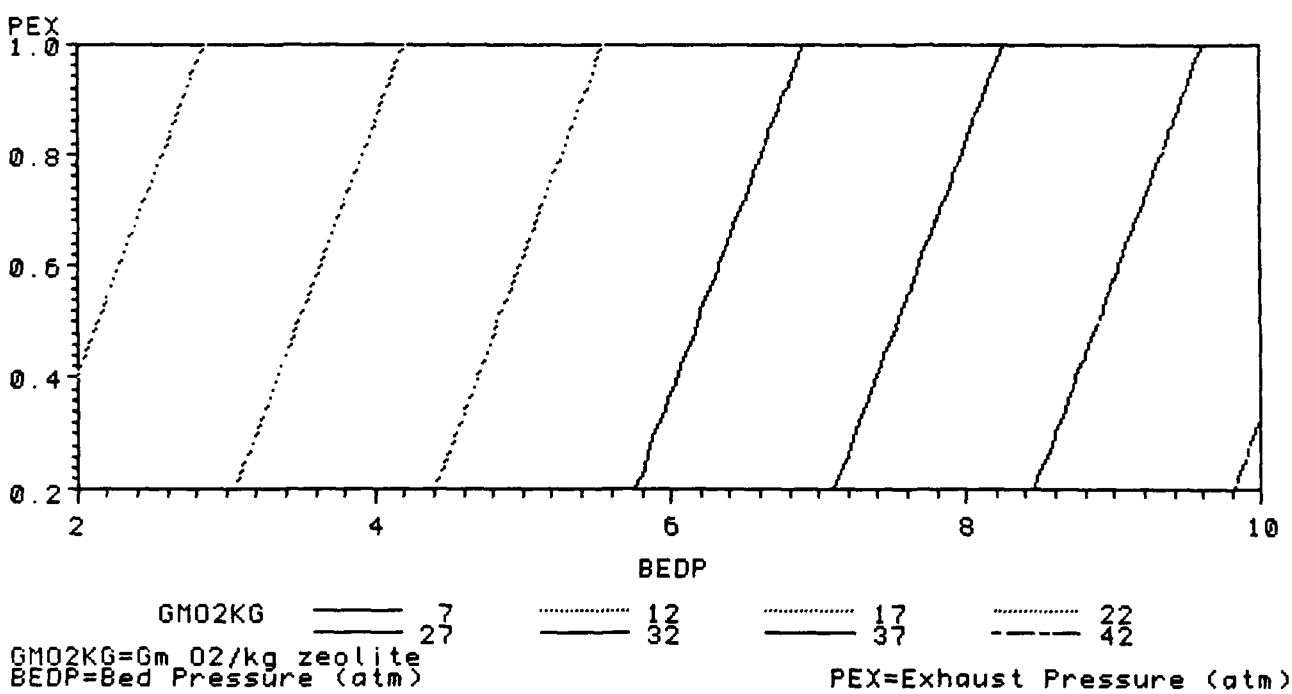


Figure 13. OxySieve-5 multiple regression surface, T=298 K--contours.

Unfortunately, it is not possible to extrapolate any of this information using the just mentioned models because they have no physical basis. However, if the total mass delivered is corrected by the amount of oxygen delivered from the voids in the bed, the contribution of the adsorbed amount to the total can be found. Isotherm parameters can then be derived from the data. A model based on this information can be extrapolated with more confidence because of its physical basis.

Equation (1) can be rewritten as:

$$n_{net} = n_{gas} + n_{ads} \tag{3}$$

where n_{gas} is a function of the gas, the void fraction, and the bulk density of the zeolite.

The void fraction can be found from (5):

$$\frac{\rho_{Bed}}{\rho_P} = 1 - \varepsilon \tag{4}$$

where ρ_P is the particle density. Table 6 summarizes these calculations for zeolite 5A and OxySieve-5. The particle densities are as indicated by Union Carbide (the value shown for OxySieve-5 is that for MG3 (13X)). The bulk ("snowstorm packed") densities are as measured at the University of Texas.

TABLE 6. SOLID PROPERTIES

Zeolite type	ρ_{bed} (g/cm^3 bed)	ρ_P (g/cm^3 particle)	ε (cm^3 unpacked/cm^3 bed)
5A	0.789	1.57	0.500
OxySieve-5	0.711	1.53	0.535

Using the Ideal Gas Law with compressibility factor z, n_{gas} can be expressed as:

$$n_{gas} = \frac{\varepsilon}{\rho_{Bed}} \left(\frac{MW_{O2}}{z\,RT} \right) \left(P_{op} - P_{vent} \right) \tag{5}$$

For the temperatures and pressures in this investigation, $z = 1$.

These experiments actually measure desorption of oxygen from the zeolite bed. If no hysteresis is assumed in the adsorption-desorption cycle, parameters for the adsorption isotherm can be found. For Langmuir isotherms, n_{ads} can be expressed as:

$$n_{ads} = \frac{k_1 n_{sat} P_{op}}{1 + k_1 P_{op}} - \frac{k_1 n_{sat} P_{vent}}{1 + k_1 P_{vent}}$$

$$= \frac{k_1 n_{sat}\left(P_{op} - P_{vent}\right)}{1 + k_1\left(P_{op} + P_{vent}\right) + k_1^2 P_{op} P_{vent}}$$

$$= \frac{k e^{\left(\frac{-\Delta H}{RT}\right)} n_{sat}\left(P_{op} - P_{vent}\right)}{1 + k e^{\left(\frac{-\Delta H}{RT}\right)}\left(P_{op} + P_{vent}\right) + k^2 e^{\left(\frac{-2\Delta H}{RT}\right)} P_{op} P_{vent}} \qquad (6)$$

assuming the usual van't Hoff temperature dependence for the Henry's Law constant.

Summing Equations (5) and (6) gives:

$$n_{net} = \frac{\varepsilon}{\rho_{Bed}}\left(\frac{MW_{O2}}{z\,RT}\right)\left(P_{op} - P_{vent}\right) +$$

$$\frac{k e^{\left(\frac{-\Delta H}{RT}\right)} n_{sat}\left(P_{op} - P_{vent}\right)}{1 + k e^{\left(\frac{-\Delta H}{RT}\right)}\left(P_{op} + P_{vent}\right) + k^2 e^{\left(\frac{-2\Delta H}{RT}\right)} P_{op} P_{vent}} \qquad (7)$$

Equation (7) is a more meaningful way to represent the data in these experiments than either the quadratic or the multiple regression surfaces.

However, the estimation of the parameters in this equation is significantly more difficult than estimation of the parameters for the quadratic and multiple regression surfaces. In fact, the usual nonlinear optimization methods failed to find parameters for Equation (7) given the data in these experiments. This failure is probably due to the relatively limited temperature range of the data. Therefore, an analytical solution was

attempted whereby data would be applied in triplets to Equation (7) to give multiple sets of three equations with three unknowns (the parameters k, n_{sat}, and ΔH). Unfortunately, the resultant nonlinear algebraic equation for ΔH (for a simplified case neglecting the $P_{op}P_{vent}$ term in the denominator of Equation (7)) yielded nonphysical results.

Thus, it was decided to adopt the heats of adsorption as reported by Miller (6,7) and to correlate the data using only k and n_{sat}. Two approaches were taken. In the first approach, all 45 possible combinations of distinct pairs of the ten data points were considered in solving for k and n_{sat}. Obviously nonphysical results were discarded (such as k less than zero). In the second approach, only the eight pairs of data taken at the same temperature were considered. It was believed that the error from the adoption of literature values for the heats of adsorption could be minimized in this way. For each approach, the resultant set of parameter values was averaged and the standard deviations found. Table 7 summarizes the results of the calculations; the complete table is included in Appendix E. Note that the average and standard deviation in the "maximum pairs" case is greatly affected by a small number of points that have high values.

The equation solved for k is quadratic:

$$Ak^2 + Bk + C = 0 \tag{8}$$

where

$$A = n_2 t_1 t_2^2 \left(P_{op1} - P_{vent1}\right) P_{op2} P_{vent2} - n_1 t_2 t_1^2 \left(P_{op2} - P_{vent2}\right) P_{op1} P_{vent1} \tag{9}$$

$$B = t_1 t_2 n_2 \left(P_{op2} + P_{vent2}\right)\left(P_{op1} - P_{vent1}\right) - t_1 t_2 n_1 \left(P_{op1} + P_{vent1}\right)\left(P_{op2} - P_{vent2}\right) \tag{10}$$

$$C = t_1 n_2 \left(P_{op1} - P_{vent1}\right) - t_2 n_1 \left(P_{op2} - P_{vent2}\right) \tag{11}$$

n_i is the amount adsorbed in run i, and

$$t_i = e^{\left(\frac{-\Delta H}{RT_i}\right)}$$

The equation for n_{sat} is:

$$n_{sat} = \frac{n_1\left(1 + kt_1\left(P_{op1} + P_{vent1}\right) + k^2 t_1^2 P_{op1} P_{vent1}\right)}{kt_1\left(P_{op1} + P_{vent1}\right)} \qquad (12)$$

TABLE 7. LANGMUIR PARAMETERS

Zeolite	k (atm^{-1})	σ_k	n_{sat} (gm O2/kg zeolite)	$\sigma_{n_{sat}}$
		Eight Pairs of Data Points		
5A	1.698E-4	0.324E-4	134.4	20.4
OxySieve-5	1.565E-4	0.338E-4	159.9	31.5
		Maximum Pairs of Data Points		
5A	2.119E-4	1.362E-4	140.5	86.71
OxySieve-5	5.639E-4	14.00E-4	223.2	527.32

The variation in the OxySieve-5 parameters (when all points are included) is extremely high. However, as just mentioned, this variation is primarily an effect of a few data pairs. Elimination of the eight data pairs with the highest k values reduces the standard deviation in k by a factor of almost 20 while cutting the standard deviation in n_{sat} by a factor of 12. Elimination of data in this manner is, unfortunately, arbitrary. Because the error was believed to be largely due to the heat of adsorption estimate, the values for k and n_{sat} used here have been taken from the eight pairs of data where the temperatures are the same. These surfaces and contours are presented in Figures 14-17, on the same axes as Figures 6-9.

DISCUSSION

The different models (quadratic, multiple regression, and Langmuir) are compared in Figure 18 for zeolite 5A and Figure 19 for OxySieve-5. Both the multiple regression and Langmuir models agree reasonably well with the quadratic model (the quadratic surface is

the reference because it passes through all the data). However, as indicated in Figure 20, extrapolation is physically valid only using the Langmuir model. The quadratic model gives an isotherm that is nonphysical at these pressures (although maxima are found in isotherms at pressures much higher than found in these experiments). The multiple regression isotherms are also nonphysical, as no limit on adsorbed amount is reached as bed pressure is raised.

Langmuir isotherm parameters found in this work are compared to Miller (6,7) and Ruthven (1) in Table 8. This table specifically considers parameters used in Ruthven's statistical thermodynamic isotherm. The n_{sat} values for Ruthven and Miller are derived from the estimates they use for the ratio of the volume of the zeolite cage to the volume of the oxygen molecule. The values calculated in this work (Table 8) are about 35% high for the preexponential factor in the temperature dependence of the Henry's Law constant for both the zeolite 5A and OxySieve-5 (which is compared to 13X). The limiting adsorption amounts (n_{sat}) are low compared to the estimates prepared using the volume ratios from Miller and Ruthven. The low n_{sat} amounts are expected because the pressures in these experiments were not high enough to allow a good estimate of this parameter and were certainly nowhere near a limit represented by the volume ratios. The Langmuir isotherm using parameters from this work is compared to Ruthven's 1976 version of the statistical thermodynamic isotherm on zeolite 5A in Figure 21.

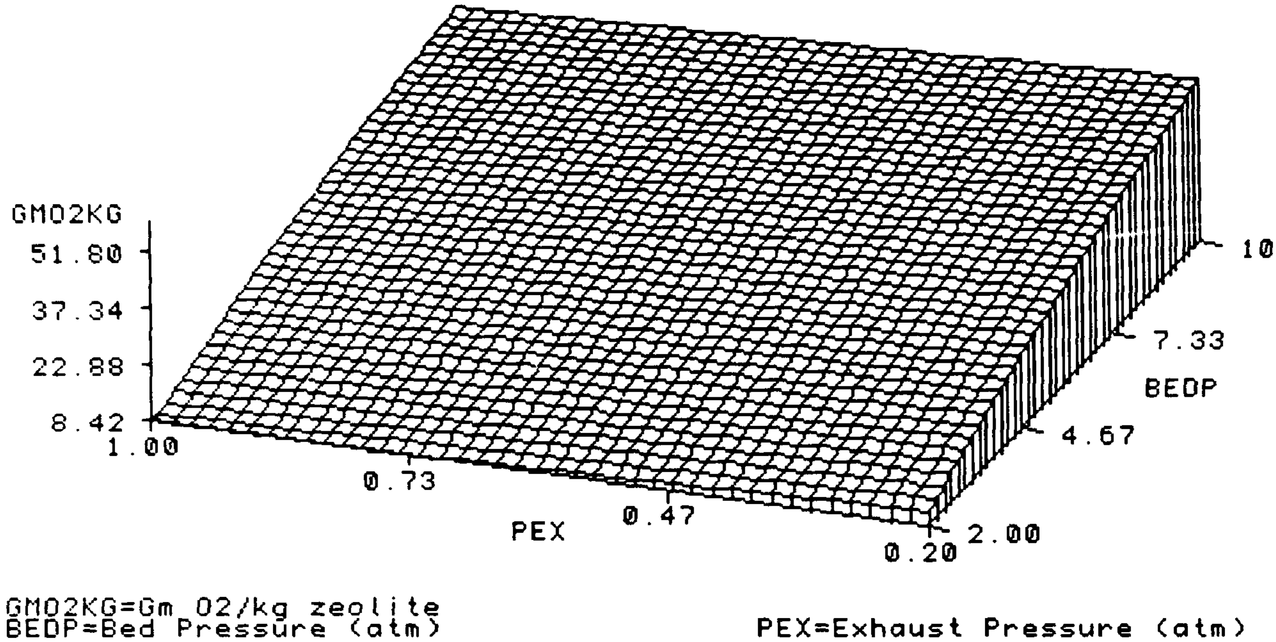


Figure 14. Zeolite 5A Langmuir surface, T=298 K.

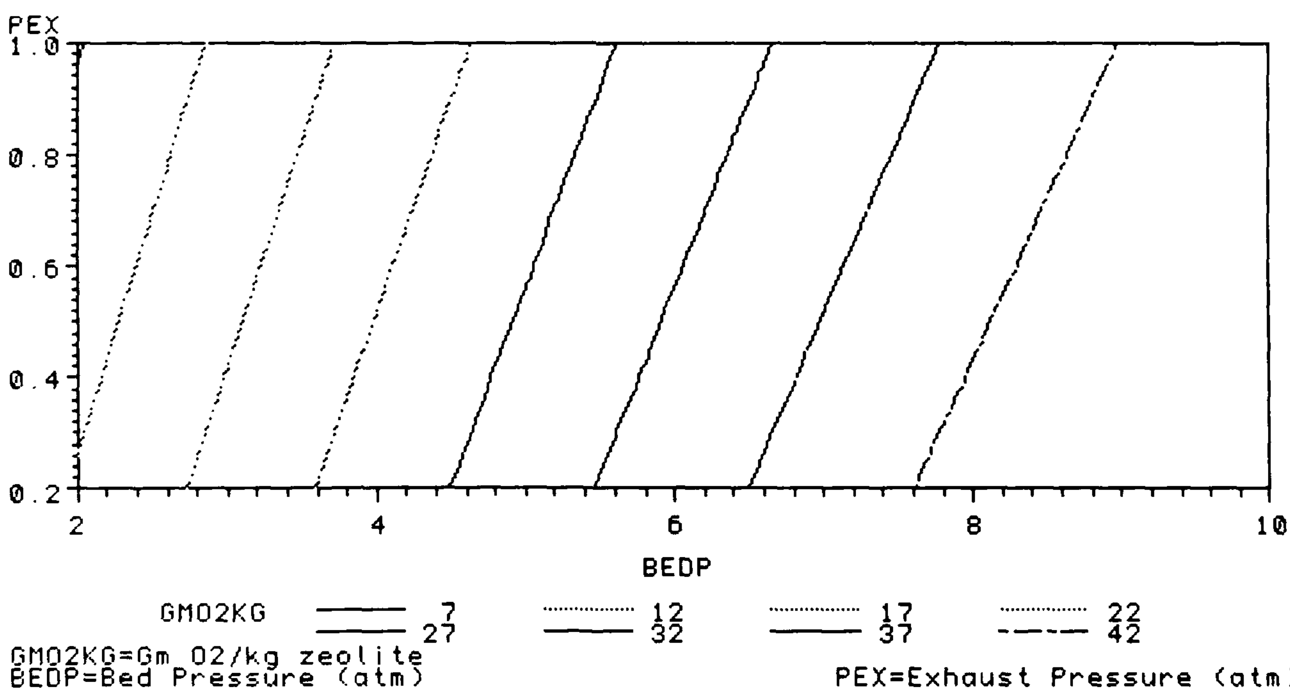


Figure 15. Zeolite 5A Langmuir surface, T=298 K--contours.

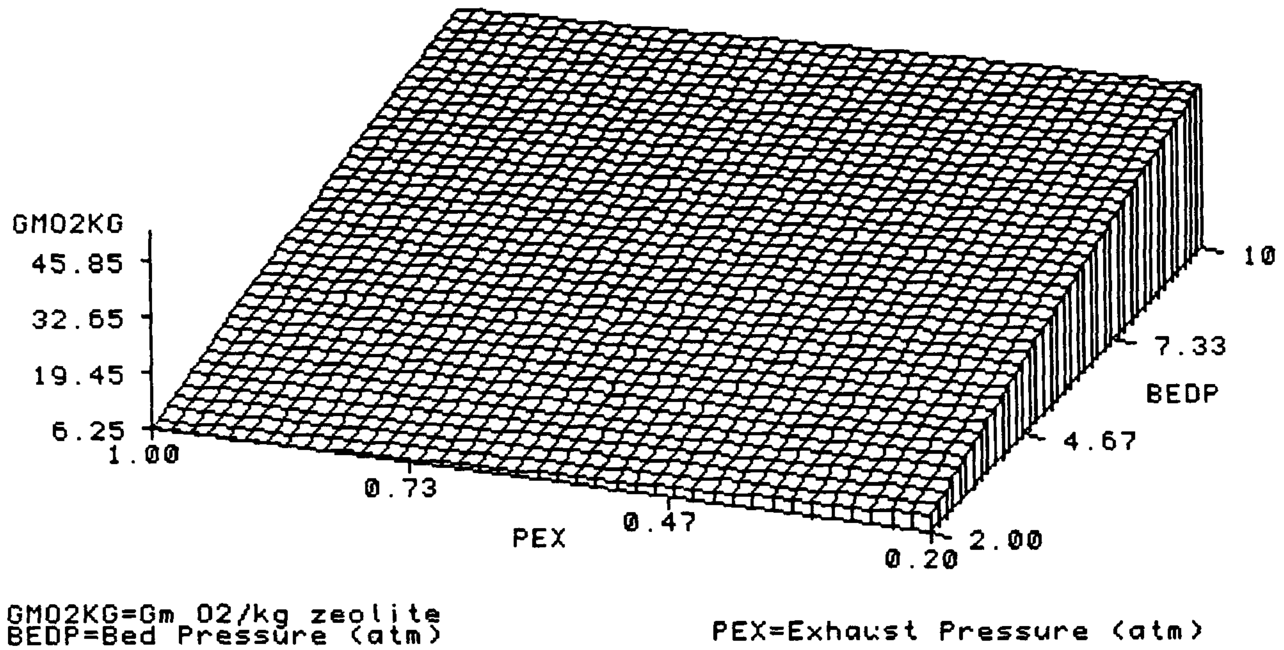


Figure 16. OxySieve-5 Langmuir surface, T=298 K.

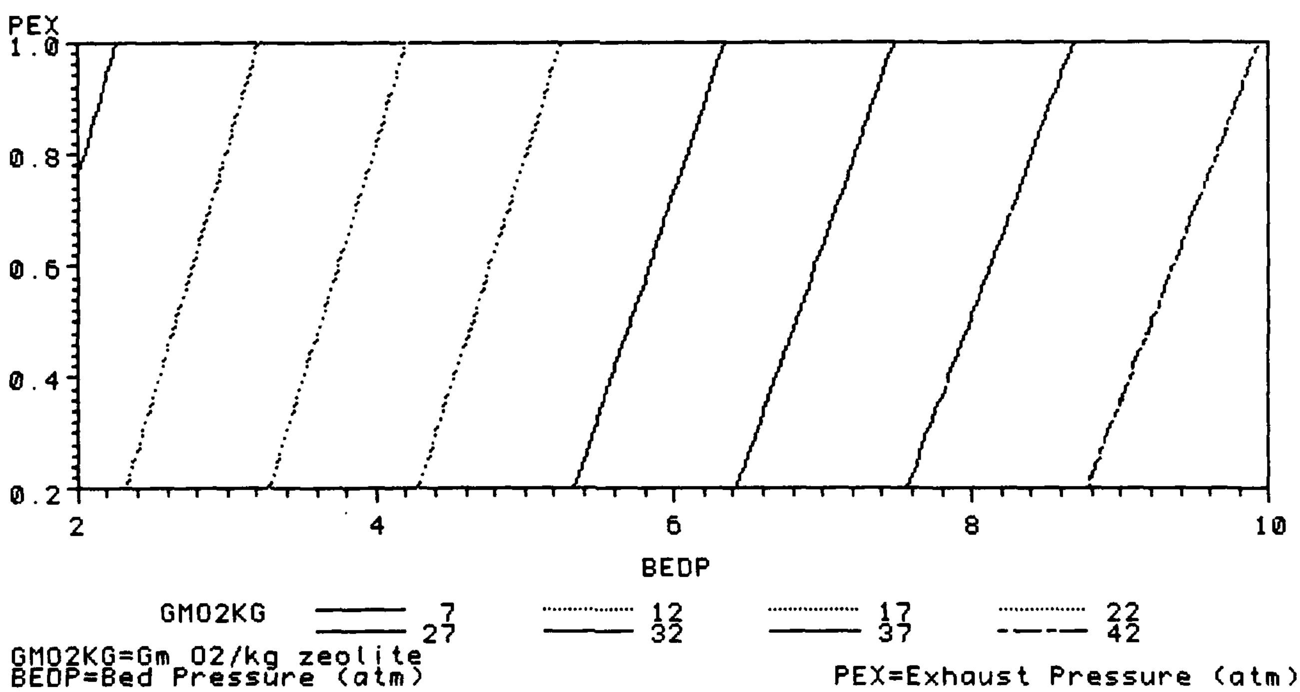


Figure 17. OxySieve-5 Langmuir surface, T=298 K--contours.

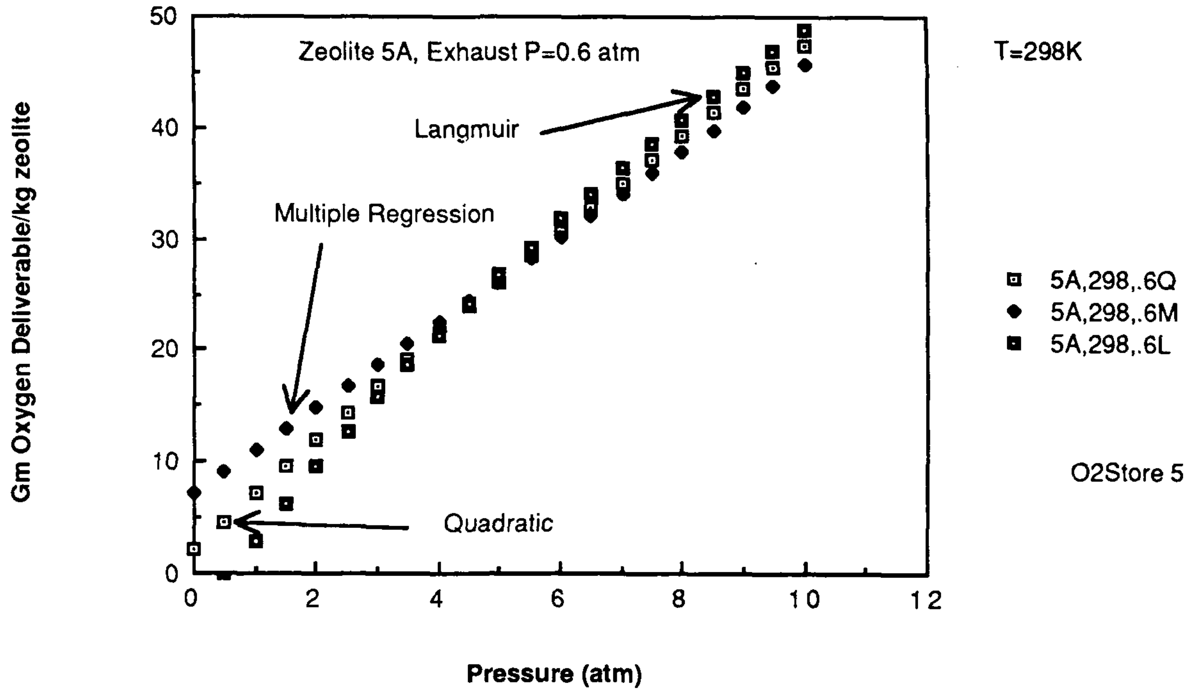


Figure 18. Model comparison--zeolite 5A.

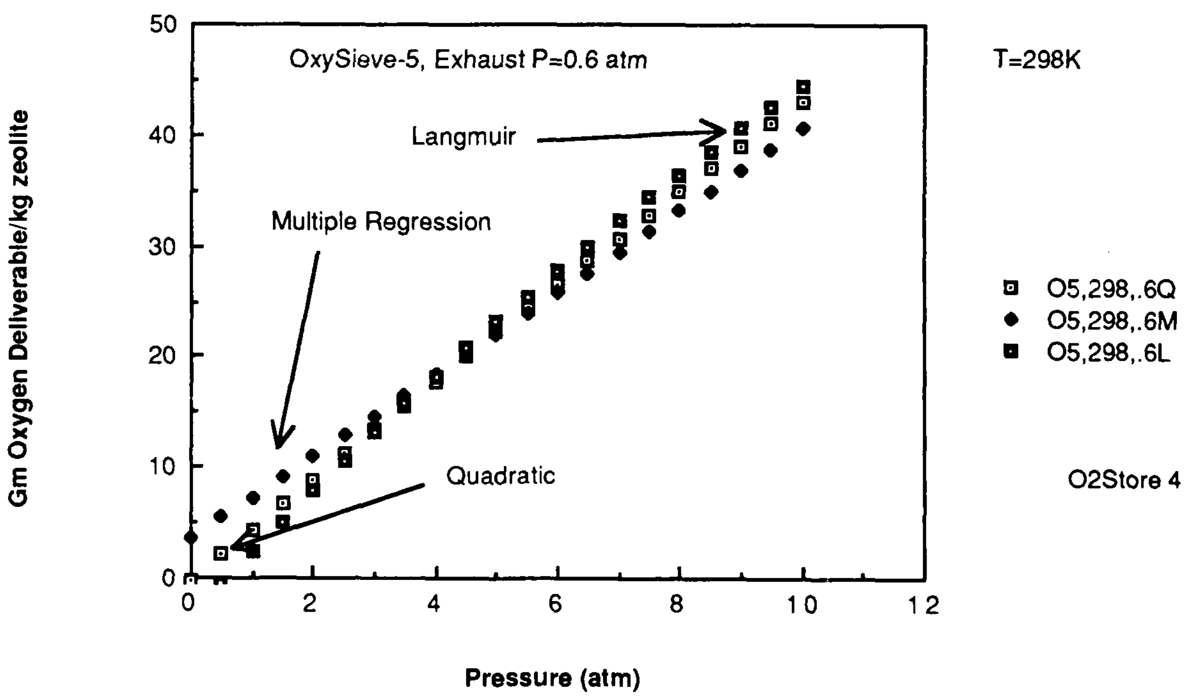


Figure 19. Model comparison--OxySieve-5.

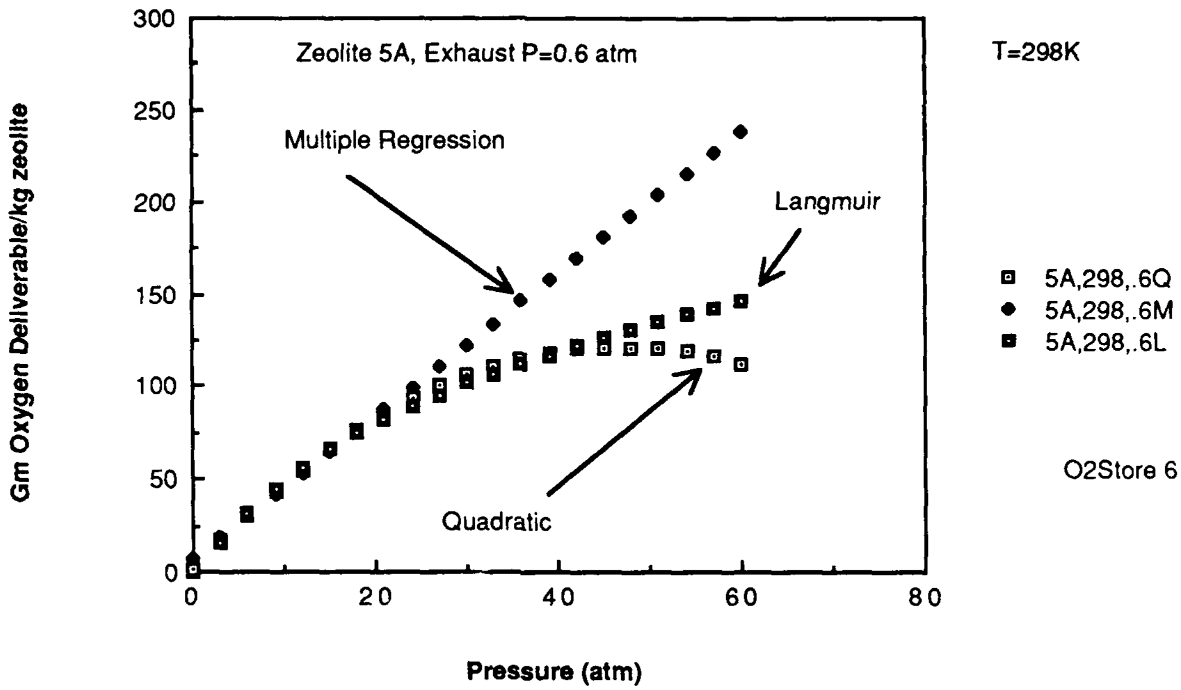


Figure 20. Model comparison--extended bed pressure range.

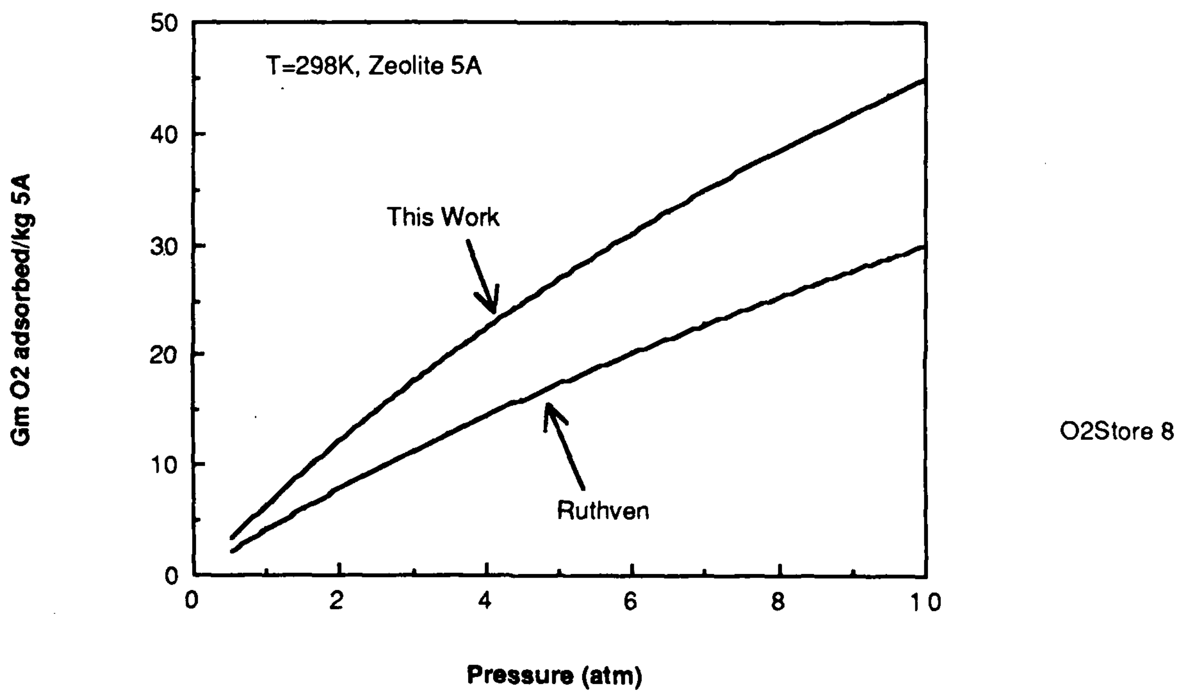


Figure 21. Statistical thermodynamic and Langmuir isotherm comparison.

TABLE 8. STATISTICAL MECHANICAL ISOTHERM PARAMETER COMPARISON

$$k = k_0 \exp\left(\frac{q_0}{RT}\right),\ n_{sat} \text{ from } \frac{\nu}{\beta}$$

Source	Zeolite type	k_0 (gm O2/kg zeolite-atm)	n_{sat} (gm O2/kg zeolite)
Miller (6)	5A	1.70E-2	318.2
Miller (7)	13X	1.69E-2	433.2
Ruthven (1)	5A	1.63E-2	230.4
This work	5A	2.28E-2	134.4
This work	OxySieve-5	2.50E-2	159.9

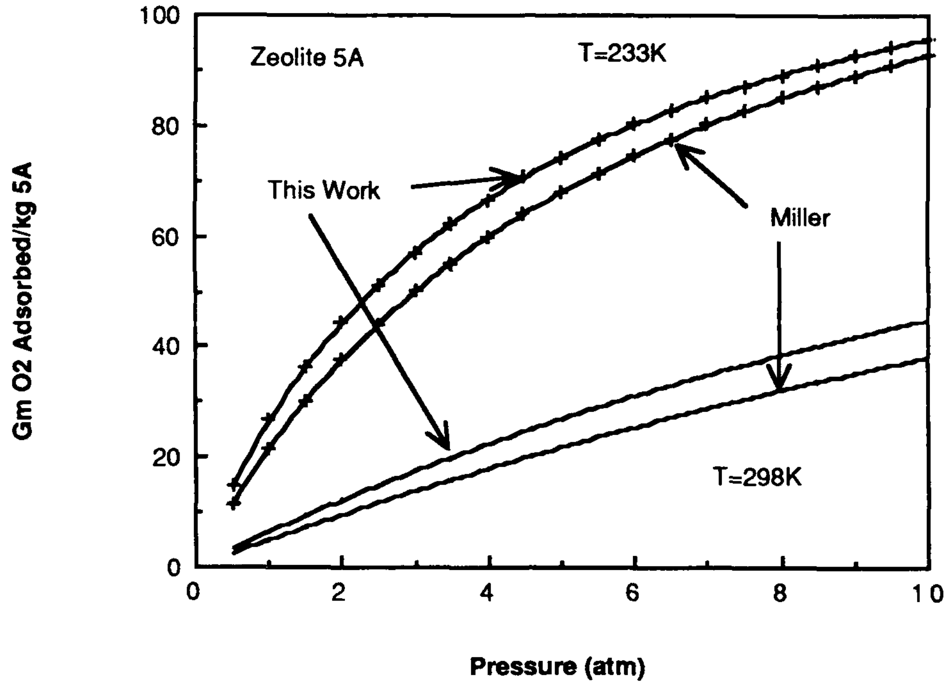
Table 9 compares values reported by Miller for a Langmuir model of oxygen adsorption on zeolites 5A and 13X with those from this work. The agreement in parameters for zeolite 5A is better than the agreement between OxySieve-5 and zeolite 13X, as is expected. It should be noted that the parameters *a* and *b* in Miller's implementation of the Langmuir isotherm are uncorrelated, while the parameters in this work are linearly correlated. In general, the Langmuir isotherm is given by:

$$\theta = \frac{n}{n_{sat}} = \frac{kP}{1 + kP} \tag{13}$$

Therefore,

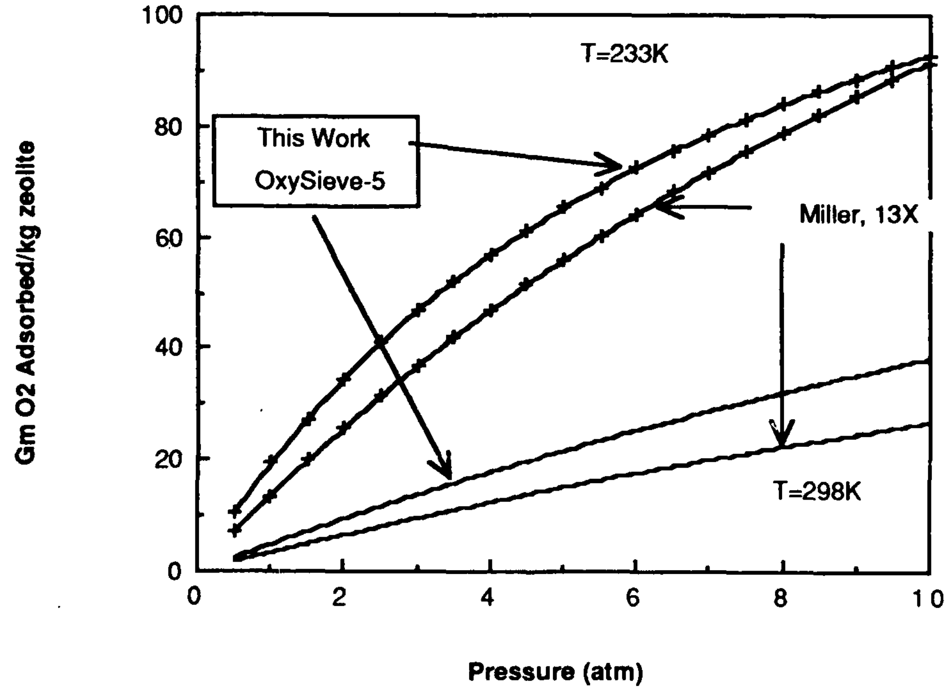
$$n = \frac{k n_{sat} P}{1 + kP} \tag{14}$$

which relates Miller's *a* and *b* linearly provided n_{sat} is assumed to be invariant with temperature. Miller does not make this assumption, perhaps because the temperature range in his experiments is much broader than the temperature range in this work. Because of the small temperature range in this work, the assumption of an invariant n_{sat} with temperature was made. Figure 22 compares Miller's Langmuir isotherm with that of this work at two temperatures on zeolite 5A. Figure 23 makes the same comparison for OxySieve-5 and zeolite 13X. Note that the 233 K isotherms represent extrapolation of the model in this paper, while the pressures greater than 4 atmospheres are extrapolations of the Miller isotherms. Also, in this work no data were taken for pressures below about 2 atmospheres.



O2Store 9

Figure 22. Langmuir isotherm comparison--zeolite 5A.



O2Store 10

Figure 23. Langmuir isotherm comparison--zeolite 13X and OxySieve-5.

TABLE 9. COMPARISON OF LANGMUIR PARAMETERS

$$n = \frac{aP}{1 + bP}$$

a = [gm O2/kg zeolite-atm], b = [1/atm]

Zeolite/Temp.	a_{Miller}	$a_{This\ Work}$	b_{Miller}	$b_{This\ Work}$
5A/298 K	5.13	6.76	.0345	.0503
5A/233 K	25.4	33.1	.174	.246
5A/203 K	72.0	97.0	.426	.722
OxySieve-5/323 K	2.28	3.33	.0069	.0209
OxySieve-5/297 K	3.48	5.03	.0299	.0314
OxySieve-5/233 K	14.4	22.1	.0572	.1381
OxySieve-5/203 K	41.7	60.1	.196	.376

(The OxySieve-5 data shown for Miller is actually zeolite 13X)

The reasons for the disagreement between isotherm parameters found in this work and those from Miller and Ruthven are unclear. The sensitivity of the correlations to the estimate of system unpacked volume has been checked and is not great enough (even if it is 100% low or high) to account for the deviation. The shorter settling time used (as compared to Miller) leads one to conclude that the parameters in this work should be <u>less</u> than Miller's, instead of greater. If hysteresis exists in the oxygen adsorption-desorption cycle, the parameters in this work should, again, be less than Miller's.

Because no recalibration of the MFC was done for oxygen (tables were used instead) it is possible that this affected the results. Also, a temperature gradient could have existed in the temperature box (yet no gradient could have existed at 298 K, room temperature). However, it is not believed that these effects were large enough to account for the apparent discrepancies.

Finally, Figure 24 compares the required reserve system volume (for the USAF specification of 200 liter NPT (8.2 gm-mole)) for the packed beds and unpacked beds. Exhaust pressure has been chosen as 0.6 atm and temperature is 298 K. The quadratic model is used for the packed beds, along with the bulk densities from Table 6.

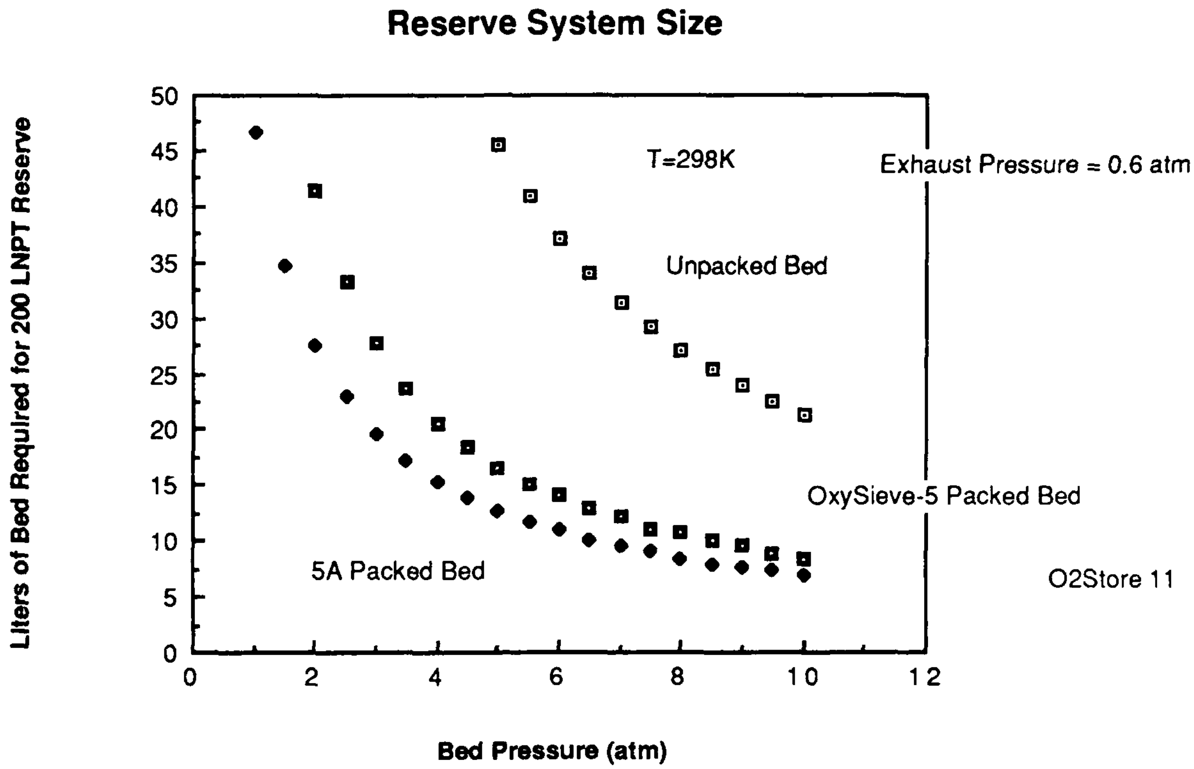


Figure 24. Volume estimates--packed and unpacked beds.

CONCLUSIONS

1. Equations have been found to estimate the required amount of zeolite for a zeolite packed reserve system over a limited range of temperature and pressures (see Tables 1-3, Equation (2), and Table 4).

2. Solid properties have been measured to allow estimation of reserve system volume (Table 6).

3. Langmuir parameters have been estimated for both zeolite 5A and OxySieve-5 and compared to literature values (Tables 7-9 and Figures

21-23). Parameters from this work are higher than values reported in the literature, for reasons that remain unclear.

4. Future experiments should be done over larger temperature ranges (to allow estimation of ΔH). Temperature distributions in the bed should be measured and eliminated.

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APPENDIX A

OXYGEN STORAGE ON ZEOLITES
(Reprint of December 1987 Report)

Progress Report: Reserve Oxygen Storage System

Introduction

The University of Texas has been contracted to develop a model for a reserve oxygen storage system that can be incorporated into an overall On Board Oxygen Generation System (OBOGS) model. Because high pressure gaseous oxygen reserve systems present a logistical problem, interest has been expressed in a reserve system that uses cylinders packed with zeolites. Packed zeolite beds can, in certain pressure/temperature regions, contain more gas than cylinders with the same volume and no zeolite.

For the F-16, a reserve system with 200 liters NPT of oxygen has been specified. This value has been used in the analysis that follows.

Progress

Progress has been hindered by the unavailability of literature data to assist in the design of an experimental system. Specifically, information was required in order to determine a pressure range of interest for analysis and experiments. Much of the required data has only become available as of November, 1987, due to translation and binding lags for the journal Izvestiya Akademii Nauk SSSR, Seriya Khimicheskaya. This journal has had a series of articles on nitrogen and oxygen high pressure adsorption on 13X (1,2,3). A detailed collection of these data has been ordered (4).

The 200 liter NPT specification corresponds to approximately 8.2 gm-mole oxygen for the reserve system. Using standard compressibility charts, required plenum volume can be found as a function of pressure for this molar oxygen requirement. Similarly, required plenum volume can be found as a function of pressure for the packed bed case once the isotherm is known.

In the absence of high pressure data on either 13X or 5A, an analysis has been done using Ruthven's statistical thermodynamics isotherm (5). Parameters for oxygen adsorption on 5A were taken from Ruthven's paper and Miller's thesis (6). The parameters for oxygen on 13X were estimated from Gorbunov, et al. (3), and Breck (7). Ruthven's isotherm has been shown to work well for oxygen on zeolite 5A at 298 K and for pressures below 5 atmospheres (5,8). However, applications of Ruthven's isotherm to zeolite 13X systems were not found. Figure 1 shows the oxygen isotherm on 5A calculated using Ruthven's statistical thermodynamic method. Agreement between the generated oxygen isotherm and the data of Miller is good for the pressure range of Miller's work. High pressure oxygen adsorption data on zeolite 5A are unavailable; therefore, for pressures above 70 psia, the analysis presented here is an extrapolation of the available data.

Generation of the 13X isotherms from the Henry constants presented in Gorbunov was not successful. While the Henry constants for oxygen on 13X can be expected to be higher than those on 5A, the calculated constants for 13X were on the order of 10^5 times those on 5A. The 13X Henry constants are expected to be higher because the main ring in the pore structure is larger, but the value of 41.5 molecules/cavity-torr obtained for oxygen exceeds the ratio of the cavity volume to molecular volume (which was 16). This does not appear to be reasonable. It should be noted that the Gorbunov paper gave 0.4 molecules per cavity as the upper limit for the Henry constants reported. There also exists the possibility that there is an error in translation. Analysis of the tabulated data may reveal any inconsistencies. Only the 5A analysis is presented here.

A comparison of required volumes for a 200 liter NPT oxygen reserve system as a function of pressure is presented in Figure 2. This figure shows that zeolite filled beds are a greater advantage at lower pressures than at higher pressures. Also, there exists a pressure where the zeolitic adsorptive capacity is insufficient to offset the amount of oxygen that is displaced by the zeolite. At pressures higher than this, a packed cylinder cannot contain as much oxygen as a cylinder whose available volume has not been reduced by the presence of the adsorbent. Figure 2 indicates that this upper pressure limit for 5A at room temperatures is about 1500 psia.

Figure 3 shows the volume comparison at lower pressures. At these pressures, the zeolite packed bed is only half the volume of the unpacked cylinder. However, the required volume for the low pressure system is still large, even with the zeolite packed bed.

The volumes indicated in Figures 2 and 3 are the smallest possible volumes and neglect residual gas in the cylinder that would remain behind in actual use. As an example, at 40 psia, an unpacked cylinder of approximately 74 liters would contain the specified reserve amount of oxygen (8.2 gm-mole). But not all of this oxygen is deliverable because the tank will be vented to ambient pressure, not vacuum. The actual required volume would be dependent on the ambient pressure; it should be calculated from the difference in gas densities between the operating (or charged) pressure of the system and the ambient pressure. Thus, the required volume for a 40 psia system venting to atmospheric pressure (i.e., 14.696 psia) is actually 118 liters, an increase of 59% over the vacuum vented system.

The zeolitic reserve volume would depend even more heavily on venting pressure. The total capacity of one liter of zeolite is the sum of the amount of gas adsorbed (a_{op}) and the gas in the voids (n_{op}). The deliverable capacity is the total capacity less the amount that remains adsorbed (a_{vent}) and in the voids (n_{vent}) at the venting pressure. For a_{xx} in [gm-mole oxygen/gm zeolite], n_{xx} in [gm-mole oxygen/liter oxygen], ε = void fraction, and

ρ_{bed} = bed density in [gm zeolite/liter of bed], we find a net capacity per liter of bed, n_{net}, as:

$$n_{net} = \varepsilon(n_{op} - n_{vent}) + \rho_{bed}(a_{op} - a_{vent})$$

The required volume of the bed would be the specified number of moles (here, 8.2 gm-mole) divided by n_{net}. The 40 psia example for the packed cylinder venting to vacuum gives a volume of about 26.3 liters. Assuming atmospheric venting increases the required volume by 65% (to 43.5 liters) because of the oxygen remaining in the cylinder.

Figure 4 shows required cylinder volume for zeolite packed cylinders at three venting pressures as a function of operating (charged) pressure. This figure concentrates on the low pressure range because venting pressure is much less important in high pressure systems (total volume is low in these systems so the amount of gas left in the cylinder at the venting pressure is less). Figure 5 shows required unpacked cylinder volume for the same venting pressures. Figures 6 and 7 compare unpacked and packed cvlinder volumes at venting pressures of 14.7 and 5.1 psia, respectively.

Finally, Figure 8 compares predicted bed volumes from Ruthven's statistical thermodynamic isotherm with volumes calculated with data from Miller's thesis.

Conclusions

Although the experimental work remains to be done, some preliminary conclusions can be drawn from the preceding analysis of zeolite 5A.

1. The excellent agreement between Miller's data and the curves generated from Ruthven's isotherm (Figure 8) indicates that information inferred from this isotherm is reliable for pressures below 70 psia.
2. Although the capacity of a packed cylinder at 20 psia is approximately three times that of an unpacked cylinder, this relative difference in capacity is not maintained as pressure increases. At high enough pressures, the volume of the unpacked cylinder becomes lower because the gas density is high enough that the adsorptive capacity of the zeolite is less than the amount of gas displaced by the zeolite.
3. The analysis indicates that a cross-over of the unpacked and packed cylinder volumes occurs at about 1500 psia (Figure 1). For equal volumes, the packed cylinder is at a disadvantage because of the additional weight of molecular sieve. Therefore, experimental work will be confined to lower pressures, where some incentive for use of packed beds seems to exist. Specifically, the experimental system will be designed for pressures up to 500 psia.

4. At low pressures, venting pressure has a significant effect on required cylinder volume.
5. The OBOGS operates best between 35 and 45 psia. A 40 psia 5A filled reserve oxygen system will be about 43.5 liters and mass 34 kg. This system size is probably unreasonable for an F-16. However, at 70 psia, the volume would be 18.5 liters; at 120 psia, the volume drops to 11.7 liters; at 300 psia, the volume would be 5.2 liters and the mass would be 4.1 kg. Thus, it may be advantageous to consider adding a compressor to the reserve system. Note that the unpacked cylinder volume at 300 psia would be 10.3 liters (all these values assume atmospheric pressure venting).
6. Zeolite 13X (NaX) holds some promise of better performance at lower pressures because it is expected that the Henry constant for oxygen adsorption will be higher than that of 5A. However, this analysis is not yet complete.
7. This analysis has assumed that only oxygen would be adsorbed on the bed; in reality, the best possible product stream from an OBOGS would be 95% oxygen with the balance primarily argon. Therefore, the values reported for 5A are probably slightly low.

Figures

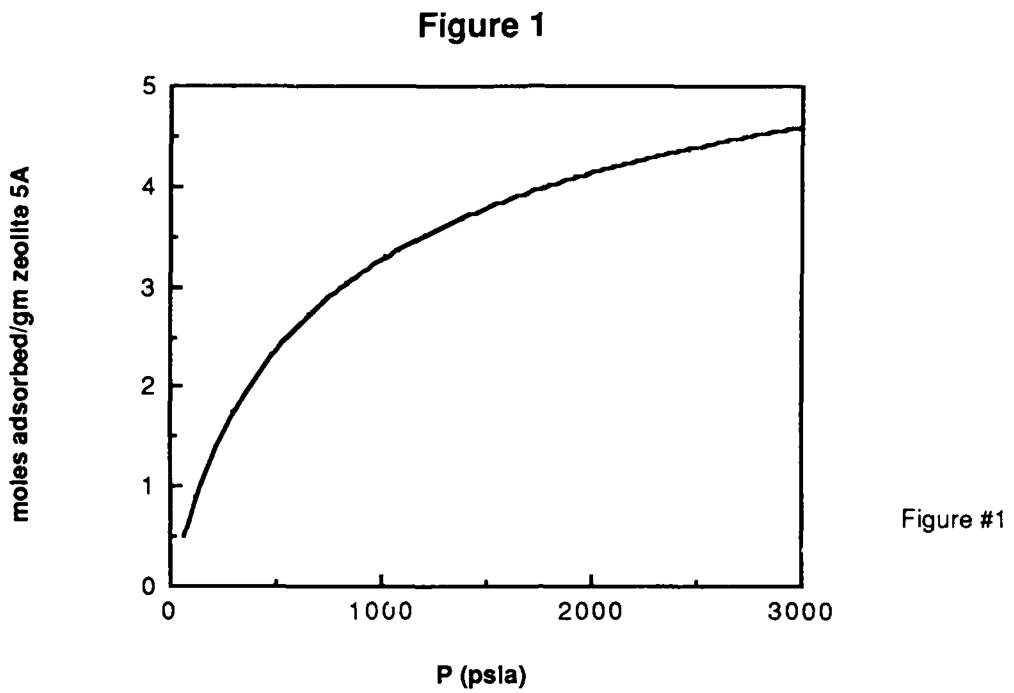


Figure 1. Oxygen Isotherm on Zeolite 5A from Ruthven's Isotherm.

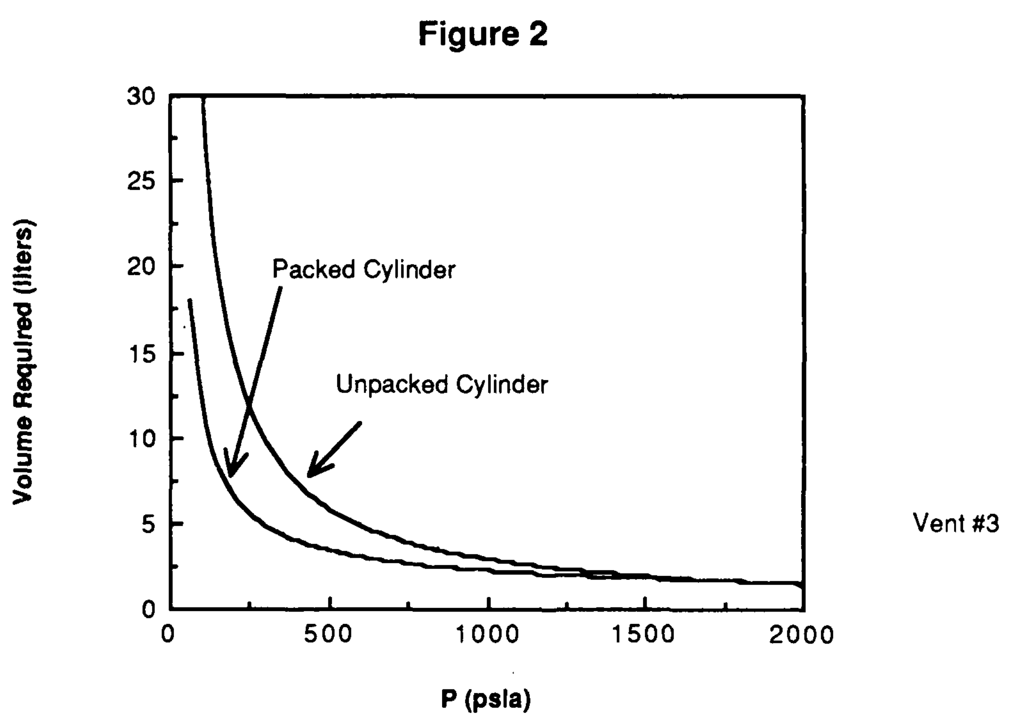
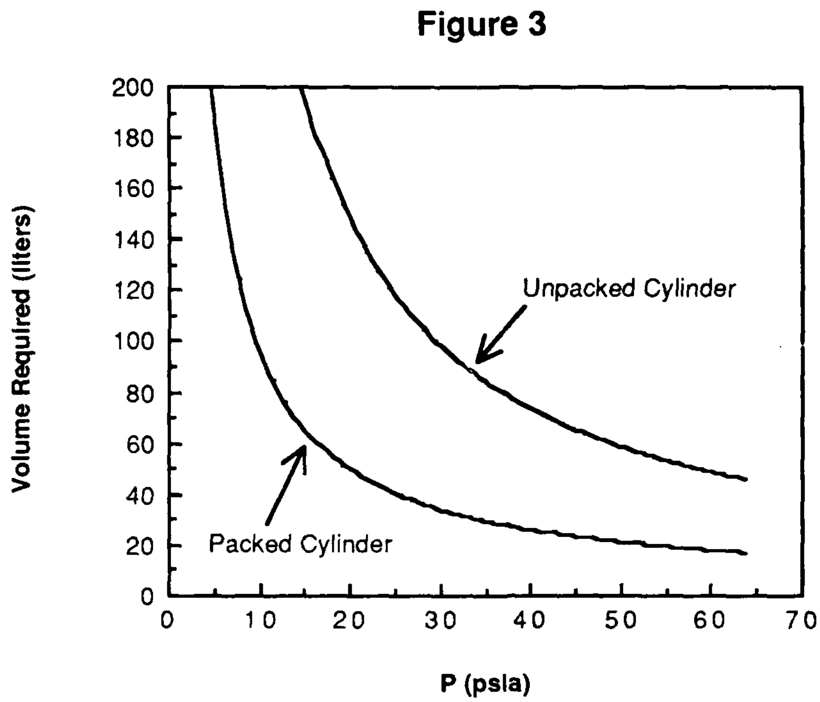
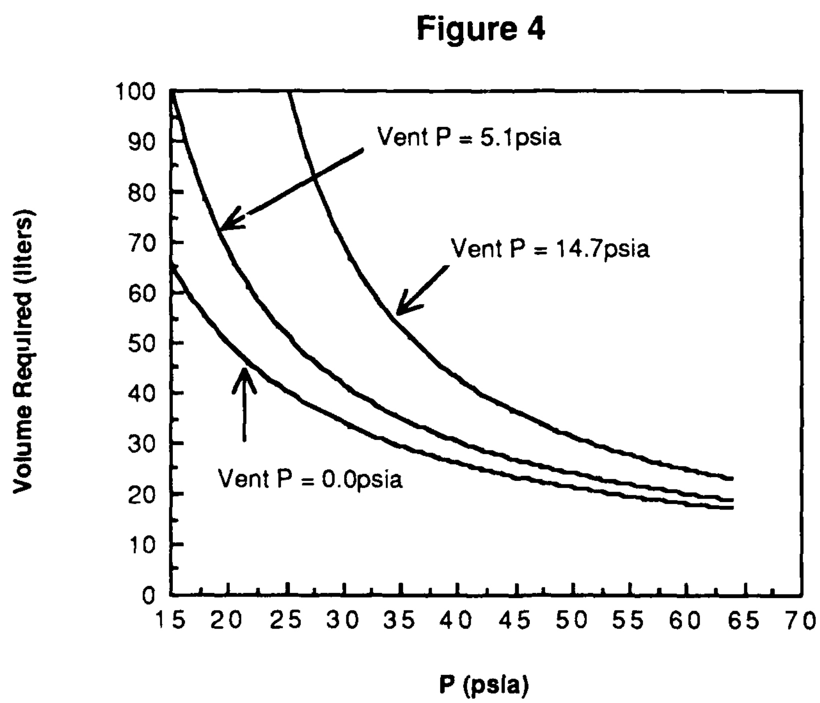


Figure 2. Comparison of Required Reserve Volumes, High Pressures.



Vent #4

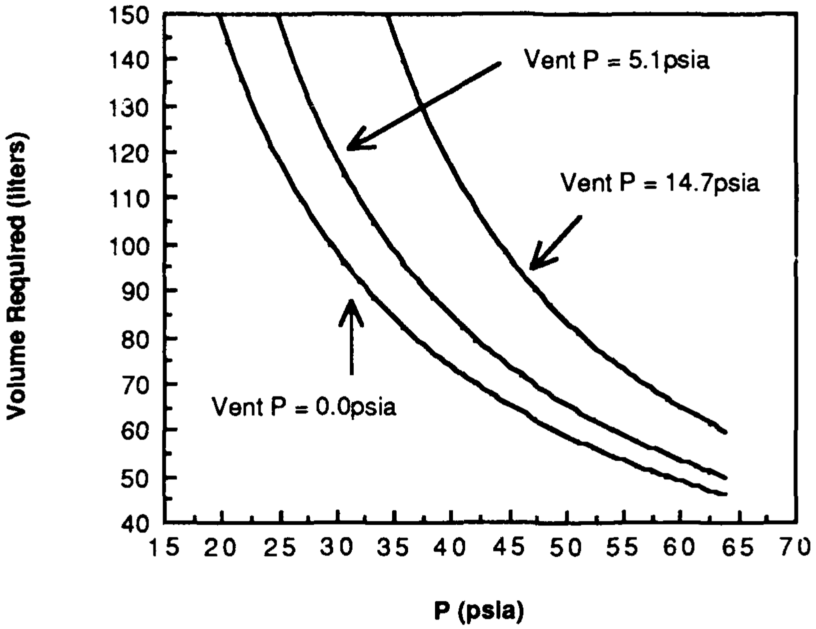
Figure 3. Comparison of Required Reserve Volumes, Low Pressures.



Vent #1

Figure 4. Required Reserve Volumes, Packed Beds, at Different Venting Pressures .

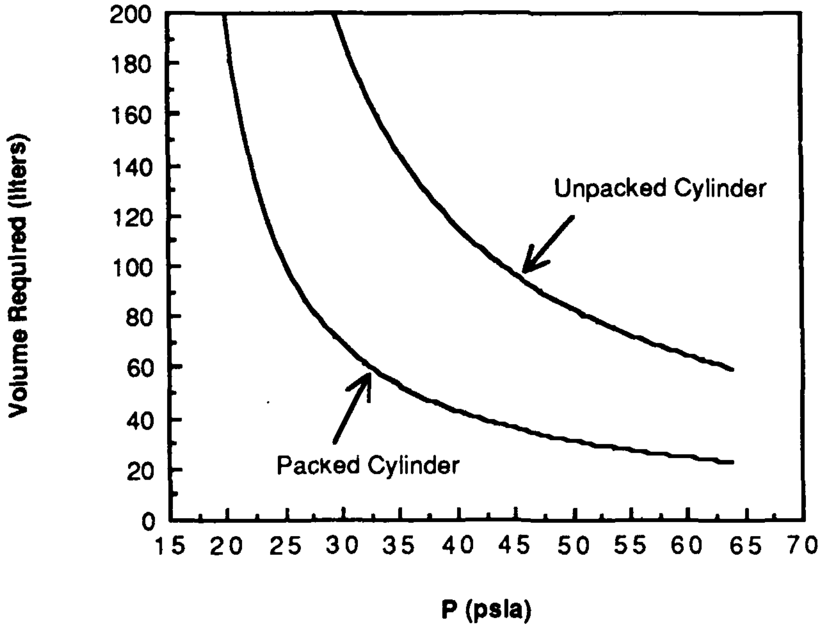
Figure 5



Vent #2

Figure 5. Required Reserve Volumes, Unpacked Beds, at Different Venting Pressures.

Figure 6



Vent #5

Figure 6. Comparison of Required Reserve Volumes, Venting Pressure = 14.7 psia.

Figure 7

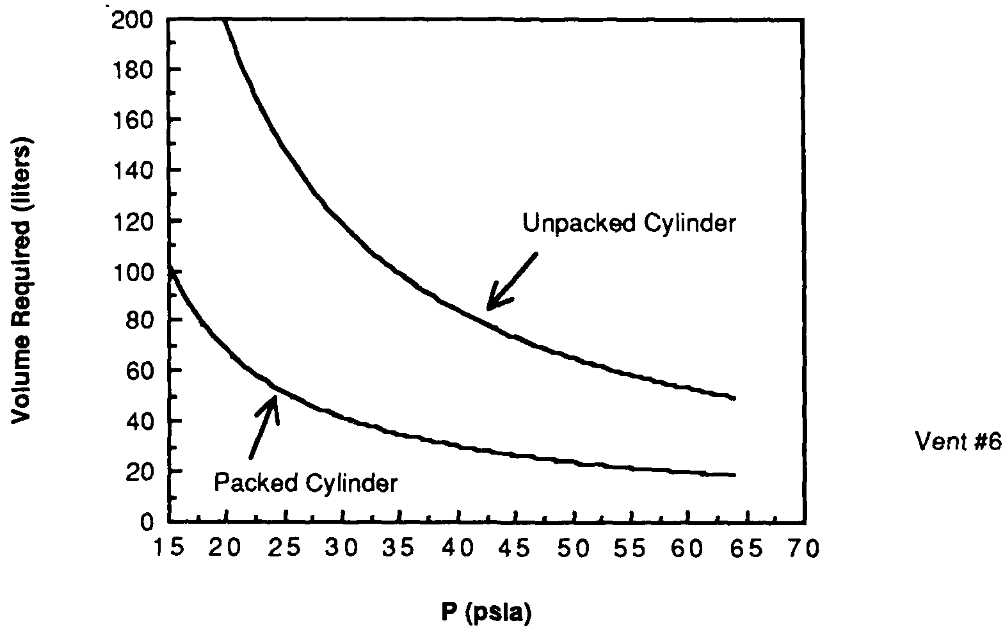


Figure 7. Comparison of Required Reserve Volumes, Venting Pressure = 5.1 psia.

Figure 8

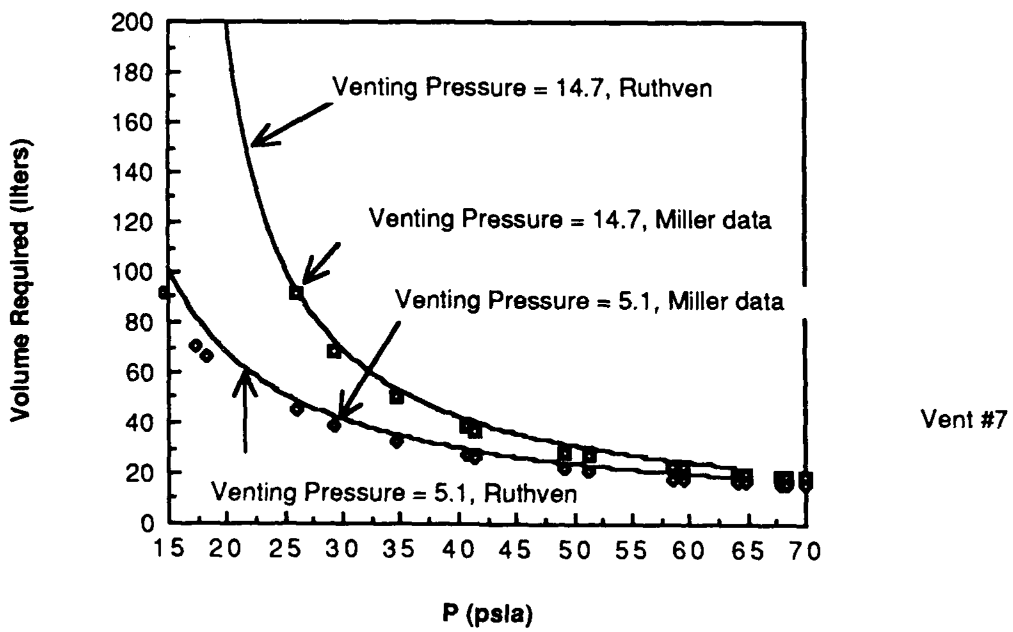


Figure 8. Comparison of Calculated Reserve Volumes from Ruthven's isotherm and Miller's data.

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Appendix A
(December 1987 Report)

Tabulated Data for Figures

The column headings are for three pressure ranges (all in psia), P_{hi}, P_{lo}, and P_{Miller}. Columns listed with the suffix "hi" go with the high pressure range, etc. The "V" columns are the required volumes for 8.179 gram moles of deliverable oxygen in the cylinder vented to the pressure listed in the column heading (the pressures are in psia). The volumes are in liters. The "Z" in the column heading indicates that the values are for a zeolite packed bed. Columns without the "Z" are values for unpacked beds (except for the "mil" columns, which are all values for packed beds using the isotherm data of Miller).

	P hi,psia	P lo,psia	V,Z,14.7,lo	V,Z,10.2,lo	V,Z,5.1,lo	V,Z,2.55,lo
1	59.9442	1.2762	-.7333E+02	-.1086E+03	-.2493E+03	-.7415E+03
2	119.8884	2.5525	-.8138E+02	-.1272E+03	-.3756E+03	0.3223E+07
3	179.8326	3.8287	-.9131E+02	-.1533E+03	-.7546E+03	0.7476E+03
4	239.7769	5.1049	-.1039E+03	-.1925E+03	0.1611E+07	0.3754E+03
5	299.7210	6.3812	-.1203E+03	-.2577E+03	0.7605E+03	0.2514E+03
6	359.6653	7.6574	-.1427E+03	-.3881E+03	0.3817E+03	0.1893E+03
7	419.6095	8.9336	-.1750E+03	-.7792E+03	0.2556E+03	0.1521E+03
8	479.5537	10.2099	-.2258E+03	0.8057E+06	0.1924E+03	0.1272E+03
9	539.4979	11.4861	-.3166E+03	0.7865E+03	0.1546E+03	0.1095E+03
0	599.4421	12.7623	-.5306E+03	0.3929E+03	0.1292E+03	0.9611E+02
1	659.3863	14.0385	-.1588E+04	0.2631E+03	0.1112E+03	0.8577E+02
2	719.3305	15.3148	0.1625E+04	0.1982E+03	0.9764E+02	0.7749E+02
3	779.2748	16.5910	0.5375E+03	0.1590E+03	0.8706E+02	0.7067E+02
4	839.2189	17.8672	0.3240E+03	0.1330E+03	0.7866E+02	0.6504E+02
5	899.1631	19.1435	0.2319E+03	0.1144E+03	0.7174E+02	0.6024E+02
6	959.1074	20.4197	0.1809E+03	0.1004E+03	0.6598E+02	0.5612E+02
7	1019.0516	21.6959	0.1485E+03	0.8956E+02	0.6112E+02	0.5256E+02
8	1078.9958	22.9722	0.1259E+03	0.8082E+02	0.5692E+02	0.4943E+02
9	1138.9399	24.2484	0.1095E+03	0.7374E+02	0.5332E+02	0.4669E+02
0	1198.8842	25.5246	0.9692E+02	0.6781E+02	0.5014E+02	0.4423E+02
1	1258.8285	26.8009	0.8692E+02	0.6275E+02	0.4732E+02	0.4203E+02
2	1318.7726	28.0771	0.7890E+02	0.5847E+02	0.4484E+02	0.4006E+02
3	1378.7169	29.3533	0.7224E+02	0.5473E+02	0.4261E+02	0.3827E+02
4	1438.6610	30.6296	0.6662E+02	0.5144E+02	0.4059E+02	0.3663E+02
5	1498.6052	31.9058	0.6184E+02	0.4854E+02	0.3877E+02	0.3514E+02
6	1558.5496	33.1820	0.5774E+02	0.4598E+02	0.3711E+02	0.3377E+02
7	1618.4938	34.4583	0.5418E+02	0.4369E+02	0.3561E+02	0.3252E+02
8	1678.4379	35.7345	0.5103E+02	0.4162E+02	0.3422E+02	0.3136E+02
9	1738.3821	37.0107	0.4822E+02	0.3973E+02	0.3293E+02	0.3028E+02
0	1798.3263	38.2869	0.4573E+02	0.3803E+02	0.3175E+02	0.2928E+02
1	1858.2705	39.5632	0.4350E+02	0.3647E+02	0.3066E+02	0.2835E+02
2	1918.2148	40.8394	0.4148E+02	0.3504E+02	0.2964E+02	0.2747E+02
3	1978.1589	42.1156	0.3965E+02	0.3373E+02	0.2870E+02	0.2666E+02
4	2038.1031	43.3919	0.3798E+02	0.3251E+02	0.2781E+02	0.2589E+02
5	2098.0474	44.6681	0.3645E+02	0.3139E+02	0.2698E+02	0.2518E+02
6	2157.9917	45.9443	0.3505E+02	0.3034E+02	0.2621E+02	0.2450E+02
7	2217.9358	47.2206	0.3376E+02	0.2936E+02	0.2548E+02	0.2386E+02
8	2277.8799	48.4968	0.3256E+02	0.2845E+02	0.2479E+02	0.2325E+02
9	2337.8242	49.7730	0.3145E+02	0.2760E+02	0.2414E+02	0.2268E+02
0	2397.7683	51.0493	0.3041E+02	0.2680E+02	0.2353E+02	0.2214E+02
1	2457.7126	52.3255	0.2945E+02	0.2605E+02	0.2295E+02	0.2163E+02
2	2517.6570	53.6017	0.2855E+02	0.2535E+02	0.2240E+02	0.2114E+02
3	2577.6011	54.8780	0.2770E+02	0.2467E+02	0.2187E+02	0.2067E+02
4	2637.5452	56.1542	0.2691E+02	0.2404E+02	0.2137E+02	0.2022E+02
5	2697.4895	57.4304	0.2617E+02	0.2345E+02	0.2090E+02	0.1980E+02
6	2757.4338	58.7066	0.2547E+02	0.2288E+02	0.2045E+02	0.1940E+02
7	2817.3779	59.9829	0.2480E+02	0.2235E+02	0.2002E+02	0.1901E+02
8	2877.3220	61.2591	0.2417E+02	0.2183E+02	0.1961E+02	0.1864E+02
9	2937.2664	62.5353	0.2358E+02	0.2135E+02	0.1922E+02	0.1828E+02
0	2997.2104	63.8116	0.2301E+02	0.2089E+02	0.1884E+02	0.1794E+02

	V,Z,0.0,lo	V,Z,14.7,hi	V,Z,10.2,hi	V,Z,5.1,hi	V,Z,2.55,hi	V,Z,0.0,hi
1	0.7346E+03	0.2482E+02	0.2236E+02	0.2004E+02	0.1902E+02	0.1809E+02
2	0.3690E+03	0.1166E+02	0.1109E+02	0.1048E+02	0.1020E+02	0.9923E+01
3	0.2471E+03	0.7993E+01	0.7719E+01	0.7422E+01	0.7278E+01	0.7137E+01
4	0.1861E+03	0.6261E+01	0.6092E+01	0.5905E+01	0.5813E+01	0.5723E+01
5	0.1495E+03	0.5247E+01	0.5128E+01	0.4994E+01	0.4929E+01	0.4864E+01
6	0.1251E+03	0.4577E+01	0.4486E+01	0.4384E+01	0.4333E+01	0.4283E+01
7	0.1077E+03	0.4097E+01	0.4024E+01	0.3942E+01	0.3901E+01	0.3860E+01
8	0.9461E+02	0.3736E+01	0.3675E+01	0.3606E+01	0.3572E+01	0.3538E+01
9	0.8446E+02	0.3453E+01	0.3401E+01	0.3342E+01	0.3313E+01	0.3283E+01
10	0.7625E+02	0.3224E+01	0.3178E+01	0.3127E+01	0.3101E+01	0.3075E+01
11	0.6959E+02	0.3034E+01	0.2993E+01	0.2948E+01	0.2925E+01	0.2902E+01
12	0.6404E+02	0.2872E+01	0.2836E+01	0.2795E+01	0.2775E+01	0.2754E+01
13	0.5931E+02	0.2734E+01	0.2701E+01	0.2664E+01	0.2645E+01	0.2626E+01
14	0.5529E+02	0.2614E+01	0.2584E+01	0.2549E+01	0.2532E+01	0.2515E+01
15	0.5178E+02	0.2507E+01	0.2479E+01	0.2448E+01	0.2432E+01	0.2416E+01
16	0.4871E+02	0.2413E+01	0.2387E+01	0.2358E+01	0.2343E+01	0.2328E+01
17	0.4601E+02	0.2328E+01	0.2304E+01	0.2277E+01	0.2263E+01	0.2249E+01
18	0.4359E+02	0.2251E+01	0.2229E+01	0.2203E+01	0.2190E+01	0.2177E+01
19	0.4144E+02	0.2181E+01	0.2160E+01	0.2136E+01	0.2124E+01	0.2112E+01
20	0.3950E+02	0.2117E+01	0.2097E+01	0.2074E+01	0.2063E+01	0.2052E+01
21	0.3773E+02	0.2058E+01	0.2039E+01	0.2018E+01	0.2007E+01	0.1996E+01
22	0.3614E+02	0.2004E+01	0.1986E+01	0.1966E+01	0.1955E+01	0.1945E+01
23	0.3467E+02	0.1953E+01	0.1936E+01	0.1917E+01	0.1907E+01	0.1897E+01
24	0.3332E+02	0.1906E+01	0.1890E+01	0.1871E+01	0.1862E+01	0.1853E+01
25	0.3208E+02	0.1861E+01	0.1846E+01	0.1829E+01	0.1820E+01	0.1811E+01
26	0.3094E+02	0.1820E+01	0.1806E+01	0.1789E+01	0.1780E+01	0.1772E+01
27	0.2989E+02	0.1781E+01	0.1767E+01	0.1751E+01	0.1743E+01	0.1735E+01
28	0.2890E+02	0.1744E+01	0.1731E+01	0.1716E+01	0.1708E+01	0.1700E+01
29	0.2798E+02	0.1710E+01	0.1697E+01	0.1682E+01	0.1675E+01	0.1667E+01
30	0.2712E+02	0.1677E+01	0.1665E+01	0.1650E+01	0.1643E+01	0.1636E+01
31	0.2632E+02	0.1645E+01	0.1634E+01	0.1620E+01	0.1613E+01	0.1606E+01
32	0.2557E+02	0.1616E+01	0.1604E+01	0.1591E+01	0.1584E+01	0.1577E+01
33	0.2486E+02	0.1587E+01	0.1576E+01	0.1564E+01	0.1557E+01	0.1551E+01
34	0.2420E+02	0.1560E+01	0.1550E+01	0.1537E+01	0.1531E+01	0.1525E+01
35	0.2357E+02	0.1535E+01	0.1524E+01	0.1512E+01	0.1506E+01	0.1500E+01
36	0.2297E+02	0.1510E+01	0.1500E+01	0.1488E+01	0.1482E+01	0.1476E+01
37	0.2241E+02	0.1486E+01	0.1476E+01	0.1465E+01	0.1459E+01	0.1454E+01
38	0.2187E+02	0.1463E+01	0.1454E+01	0.1443E+01	0.1437E+01	0.1432E+01
39	0.2137E+02	0.1441E+01	0.1432E+01	0.1422E+01	0.1416E+01	0.1411E+01
40	0.2089E+02	0.1420E+01	0.1411E+01	0.1401E+01	0.1396E+01	0.1391E+01
41	0.2043E+02	0.1400E+01	0.1391E+01	0.1381E+01	0.1376E+01	0.1371E+01
42	0.1999E+02	0.1380E+01	0.1372E+01	0.1362E+01	0.1357E+01	0.1352E+01
43	0.1957E+02	0.1361E+01	0.1353E+01	0.1344E+01	0.1339E+01	0.1334E+01
44	0.1917E+02	0.1343E+01	0.1335E+01	0.1326E+01	0.1321E+01	0.1316E+01
45	0.1879E+02	0.1325E+01	0.1318E+01	0.1309E+01	0.1304E+01	0.1299E+01
46	0.1843E+02	0.1308E+01	0.1301E+01	0.1292E+01	0.1288E+01	0.1283E+01
47	0.1808E+02	0.1292E+01	0.1284E+01	0.1276E+01	0.1271E+01	0.1267E+01
48	0.1774E+02	0.1276E+01	0.1268E+01	0.1260E+01	0.1256E+01	0.1252E+01
49	0.1742E+02	0.1260E+01	0.1253E+01	0.1245E+01	0.1241E+01	0.1237E+01
50	0.1711E+02	0.1245E+01	0.1238E+01	0.1230E+01	0.1226E+01	0.1222E+01

	V,14.7,lo	V,10.2,lo	V,5.1,lo	V,2.55,lo	V,0.0,lo	V,14.7,hi
1	-.2190E+03	-.3294E+03	-.7687E+03	-.2307E+04	0.2303E+04	0.6496E+02
2	-.2420E+03	-.3843E+03	-.1154E+04	0.1193E+07	0.1152E+04	0.2794E+02
3	-.2705E+03	-.4613E+03	-.2312E+04	0.2299E+04	0.7677E+03	0.1780E+02
4	-.3065E+03	-.5769E+03	0.5966E+06	0.1150E+04	0.5758E+03	0.1306E+02
5	-.3535E+03	-.7697E+03	0.2294E+04	0.7672E+03	0.4606E+03	0.1031E+02
6	-.4176E+03	-.1156E+04	0.1149E+04	0.5755E+03	0.3838E+03	0.8520E+01
7	-.5101E+03	-.2321E+04	0.7667E+03	0.4604E+03	0.3290E+03	0.7259E+01
8	-.6552E+03	0.2983E+06	0.5752E+03	0.3837E+03	0.2879E+03	0.6323E+01
9	-.9157E+03	0.2285E+04	0.4603E+03	0.3289E+03	0.2559E+03	0.5601E+01
10	-.1520E+04	0.1147E+04	0.3836E+03	0.2878E+03	0.2303E+03	0.5026E+01
11	-.4471E+04	0.7657E+03	0.3288E+03	0.2558E+03	0.2094E+03	0.4559E+01
12	0.4750E+04	0.5747E+03	0.2877E+03	0.2303E+03	0.1919E+03	0.4171E+01
13	0.1551E+04	0.4599E+03	0.2558E+03	0.2093E+03	0.1772E+03	0.3844E+01
14	0.9268E+03	0.3833E+03	0.2302E+03	0.1919E+03	0.1645E+03	0.3565E+01
15	0.6609E+03	0.3286E+03	0.2093E+03	0.1771E+03	0.1535E+03	0.3323E+01
16	0.5135E+03	0.2876E+03	0.1919E+03	0.1645E+03	0.1439E+03	0.3112E+01
17	0.4199E+03	0.2557E+03	0.1771E+03	0.1535E+03	0.1355E+03	0.2926E+01
18	0.3551E+03	0.2301E+03	0.1645E+03	0.1439E+03	0.1279E+03	0.2762E+01
19	0.3077E+03	0.2092E+03	0.1535E+03	0.1355E+03	0.1212E+03	0.2614E+01
20	0.2714E+03	0.1918E+03	0.1439E+03	0.1279E+03	0.1152E+03	0.2482E+01
21	0.2428E+03	0.1771E+03	0.1354E+03	0.1212E+03	0.1097E+03	0.2362E+01
22	0.2197E+03	0.1644E+03	0.1279E+03	0.1151E+03	0.1047E+03	0.2254E+01
23	0.2005E+03	0.1535E+03	0.1212E+03	0.1097E+03	0.1001E+03	0.2155E+01
24	0.1845E+03	0.1439E+03	0.1151E+03	0.1047E+03	0.9596E+02	0.2064E+01
25	0.1708E+03	0.1354E+03	0.1096E+03	0.1001E+03	0.9212E+02	0.1981E+01
26	0.1590E+03	0.1279E+03	0.1047E+03	0.9595E+02	0.8858E+02	0.1904E+01
27	0.1487E+03	0.1212E+03	0.1001E+03	0.9211E+02	0.8530E+02	0.1833E+01
28	0.1397E+03	0.1151E+03	0.9594E+02	0.8857E+02	0.8225E+02	0.1767E+01
29	0.1317E+03	0.1096E+03	0.9211E+02	0.8529E+02	0.7942E+02	0.1705E+01
30	0.1246E+03	0.1046E+03	0.8857E+02	0.8225E+02	0.7677E+02	0.1648E+01
31	0.1182E+03	0.1001E+03	0.8529E+02	0.7941E+02	0.7429E+02	0.1594E+01
32	0.1124E+03	0.9593E+02	0.8224E+02	0.7676E+02	0.7197E+02	0.1544E+01
33	0.1072E+03	0.9209E+02	0.7940E+02	0.7429E+02	0.6979E+02	0.1497E+01
34	0.1024E+03	0.8855E+02	0.7676E+02	0.7197E+02	0.6774E+02	0.1453E+01
35	0.9806E+02	0.8527E+02	0.7428E+02	0.6979E+02	0.6580E+02	0.1411E+01
36	0.9406E+02	0.8223E+02	0.7196E+02	0.6773E+02	0.6397E+02	0.1371E+01
37	0.9037E+02	0.7939E+02	0.6978E+02	0.6580E+02	0.6224E+02	0.1334E+01
38	0.8696E+02	0.7675E+02	0.6773E+02	0.6397E+02	0.6061E+02	0.1299E+01
39	0.8379E+02	0.7427E+02	0.6579E+02	0.6224E+02	0.5905E+02	0.1265E+01
40	0.8085E+02	0.7195E+02	0.6397E+02	0.6060E+02	0.5758E+02	0.1233E+01
41	0.7811E+02	0.6977E+02	0.6224E+02	0.5905E+02	0.5617E+02	0.1203E+01
42	0.7555E+02	0.6772E+02	0.6060E+02	0.5757E+02	0.5483E+02	0.1174E+01
43	0.7315E+02	0.6579E+02	0.5905E+02	0.5617E+02	0.5356E+02	0.1147E+01
44	0.7090E+02	0.6396E+02	0.5757E+02	0.5483E+02	0.5234E+02	0.1121E+01
45	0.6878E+02	0.6223E+02	0.5617E+02	0.5356E+02	0.5118E+02	0.1096E+01
46	0.6678E+02	0.6059E+02	0.5483E+02	0.5234E+02	0.5007E+02	0.1072E+01
47	0.6490E+02	0.5904E+02	0.5355E+02	0.5118E+02	0.4900E+02	0.1049E+01
48	0.6312E+02	0.5756E+02	0.5234E+02	0.5006E+02	0.4798E+02	0.1027E+01
49	0.6144E+02	0.5616E+02	0.5117E+02	0.4900E+02	0.4700E+02	0.1006E+01
50	0.5984E+02	0.5482E+02	0.5006E+02	0.4798E+02	0.4606E+02	0.9855E+00

	V,10.2,hi	V,5.1,hi	V,2.55,hi	V,0.0,hi	P,Miller	V,14.7,mil
1	0.5909E+02	0.5359E+02	0.5121E+02	0.4903E+02	2.3011	-.7064E+02
2	0.2680E+02	0.2561E+02	0.2505E+02	0.2452E+02	4.8149	-.8840E+02
3	0.1733E+02	0.1682E+02	0.1658E+02	0.1634E+02	6.8066	-.1116E+03
4	0.1280E+02	0.1252E+02	0.1239E+02	0.1226E+02	9.5717	-.1696E+03
5	0.1015E+02	0.9976E+01	0.9891E+01	0.9806E+01	13.0910	-.5491E+03
6	0.8411E+01	0.8290E+01	0.8230E+01	0.8172E+01	14.6380	-.1449E+06
7	0.7179E+01	0.7091E+01	0.7047E+01	0.7005E+01	17.3838	0.3197E+03
8	0.6262E+01	0.6195E+01	0.6162E+01	0.6129E+01	18.2733	0.2388E+03
9	0.5553E+01	0.5500E+01	0.5474E+01	0.5448E+01	26.1047	0.9148E+02
10	0.4988E+01	0.4945E+01	0.4924E+01	0.4903E+01	29.3920	0.6799E+02
11	0.4528E+01	0.4492E+01	0.4475E+01	0.4457E+01	34.7096	0.5072E+02
12	0.4145E+01	0.4115E+01	0.4101E+01	0.4086E+01	40.7041	0.3897E+02
13	0.3822E+01	0.3797E+01	0.3784E+01	0.3772E+01	41.4002	0.3701E+02
14	0.3545E+01	0.3524E+01	0.3513E+01	0.3502E+01	49.1929	0.2844E+02
15	0.3306E+01	0.3287E+01	0.3278E+01	0.3269E+01	51.2040	0.2741E+02
16	0.3097E+01	0.3081E+01	0.3073E+01	0.3065E+01	58.4939	0.2272E+02
17	0.2913E+01	0.2899E+01	0.2891E+01	0.2884E+01	59.4415	0.2274E+02
18	0.2750E+01	0.2737E+01	0.2730E+01	0.2724E+01	64.1983	0.2035E+02
19	0.2604E+01	0.2592E+01	0.2586E+01	0.2581E+01	64.8944	0.2051E+02
20	0.2473E+01	0.2462E+01	0.2457E+01	0.2452E+01	67.8917	0.1911E+02
21	0.2354E+01	0.2344E+01	0.2340E+01	0.2335E+01	68.2977	0.1931E+02
22	0.2246E+01	0.2237E+01	0.2233E+01	0.2229E+01	69.9994	0.1846E+02
23	0.2148E+01	0.2140E+01	0.2136E+01	0.2132E+01	70.0961	0.1858E+02
24	0.2058E+01	0.2050E+01	0.2047E+01	0.2043E+01		
25	0.1975E+01	0.1968E+01	0.1965E+01	0.1961E+01		
26	0.1898E+01	0.1892E+01	0.1889E+01	0.1886E+01		
27	0.1828E+01	0.1822E+01	0.1819E+01	0.1816E+01		
28	0.1762E+01	0.1756E+01	0.1754E+01	0.1751E+01		
29	0.1701E+01	0.1696E+01	0.1693E+01	0.1691E+01		
30	0.1644E+01	0.1639E+01	0.1637E+01	0.1634E+01		
31	0.1590E+01	0.1586E+01	0.1584E+01	0.1582E+01		
32	0.1540E+01	0.1536E+01	0.1534E+01	0.1532E+01		
33	0.1494E+01	0.1490E+01	0.1488E+01	0.1486E+01		
34	0.1449E+01	0.1446E+01	0.1444E+01	0.1442E+01		
35	0.1408E+01	0.1404E+01	0.1403E+01	0.1401E+01		
36	0.1368E+01	0.1365E+01	0.1364E+01	0.1362E+01		
37	0.1331E+01	0.1328E+01	0.1327E+01	0.1325E+01		
38	0.1296E+01	0.1293E+01	0.1292E+01	0.1290E+01		
39	0.1263E+01	0.1260E+01	0.1259E+01	0.1257E+01		
40	0.1231E+01	0.1228E+01	0.1227E+01	0.1226E+01		
41	0.1201E+01	0.1198E+01	0.1197E+01	0.1196E+01		
42	0.1172E+01	0.1170E+01	0.1169E+01	0.1167E+01		
43	0.1145E+01	0.1143E+01	0.1141E+01	0.1140E+01		
44	0.1119E+01	0.1117E+01	0.1115E+01	0.1114E+01		
45	0.1094E+01	0.1092E+01	0.1091E+01	0.1090E+01		
46	0.1070E+01	0.1068E+01	0.1067E+01	0.1066E+01		
47	0.1047E+01	0.1045E+01	0.1044E+01	0.1043E+01		
48	0.1025E+01	0.1023E+01	0.1022E+01	0.1022E+01		
49	0.1004E+01	0.1002E+01	0.1002E+01	0.1001E+01		
50	0.9840E+00	0.9823E+00	0.9815E+00	0.9806E+00		

	V,10.2,mil	V,5.1,mil	V,2.55,mil	V,0.0,mil
1	-.1114E+03	-.3140E+03	-.3515E+04	0.3475E+03
2	-.1631E+03	-.2940E+04	0.3907E+03	0.1748E+03
3	-.2646E+03	0.4975E+03	0.2037E+03	0.1239E+03
4	-.1399E+04	0.1971E+03	0.1254E+03	0.8980E+02
5	0.2975E+03	0.1093E+03	0.8298E+02	0.6574E+02
6	0.1932E+03	0.9120E+02	0.7213E+02	0.5873E+02
7	0.1203E+03	0.7092E+02	0.5882E+02	0.4960E+02
8	0.1067E+03	0.6597E+02	0.5538E+02	0.4712E+02
9	0.6206E+02	0.4566E+02	0.4032E+02	0.3576E+02
10	0.5028E+02	0.3894E+02	0.3499E+02	0.3150E+02
11	0.4016E+02	0.3258E+02	0.2977E+02	0.2721E+02
12	0.3242E+02	0.2730E+02	0.2530E+02	0.2342E+02
13	0.3106E+02	0.2632E+02	0.2446E+02	0.2270E+02
14	0.2479E+02	0.2168E+02	0.2040E+02	0.1916E+02
15	0.2400E+02	0.2107E+02	0.1986E+02	0.1868E+02
16	0.2033E+02	0.1819E+02	0.1728E+02	0.1638E+02
17	0.2034E+02	0.1820E+02	0.1729E+02	0.1639E+02
18	0.1841E+02	0.1663E+02	0.1587E+02	0.1511E+02
19	0.1854E+02	0.1674E+02	0.1597E+02	0.1520E+02
20	0.1738E+02	0.1580E+02	0.1510E+02	0.1441E+02
21	0.1756E+02	0.1594E+02	0.1523E+02	0.1453E+02
22	0.1685E+02	0.1535E+02	0.1470E+02	0.1405E+02
23	0.1695E+02	0.1544E+02	0.1477E+02	0.1412E+02
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APPENDIX B

PROGRAM O2STORE

```
$storage:2
      PROGRAM O2STORE
      REAL SETFL,FLOW,TOTM,TIME1,TSEC,OLDFL
      REAL BEDP,EXHP,TEMP,TIMSET
      INTEGER IFLOW,ISETFL,ICHAN(2),IDELT,IDAT(5000)
      INTEGER MAXPT,IRESP,I,MAXPT2
      CHARACTER*14 GNAME
      CHARACTER*7 RUNNAME
C
C     This routine runs the oxygen storage blowdowns.
C     The mass flowmeter is opened, the rate recorded,
C     and the results integrated to give the total
C     amount of oxygen blown out.
C
C     The program must be linked with the LabPac software
C     to run.
C
      CALL INIT
      CALL STOD(0,0,0,0)
C     Assemble the channel array
C     The dummy channel takes up array space, so the desired
C     number of points has to be adjusted for the call to
C     the aquisition routine (doubled here, because there are
C     two channels)
      ICHAN(1)=4
      ICHAN(2)=999
C
C     Write the intro and ask for the run name
      WRITE(*,100)
      READ(*,101) RUNNAME
      WRITE(*,102)
      READ(*,*) BEDP
      IF (BEDP.LT.0) THEN
         BEDP=-BEDP
         GNAME='AirCo 0-200'
      ELSE
         GNAME='Matheson 0-100'
         END IF
      WRITE(*,103)
      READ(*,*) EXHP
      WRITE(*,104)
      READ(*,*) TEMP
      WRITE(*,106)
      READ(*,*) TIMSET
      WRITE(*,105)
      READ(*,*) SETFL
      ISETFL=NINT(SETFL*4095./687.76) - 2048
C     Note that this is good for 12 bit A/D, oxygen gas,
C     on a 0-100 SCCM mass flow controller calibrated for
C     air, 0-5 Volt output.  The 100. above is a conversion
C     factor.  For a 0-1000 SCCM MFC, the conversion would be
C     1000. instead of 100.
C     Note that now the program is set for use with a
C     0-1000 SCCM MFC calibrated for helium.  Calculation
C     of the above conversion is in Lab Book #1 page 18.
      WRITE(*,110)
      READ(*,*) IDELT
```

```
      WRITE(*,120)
      READ(*,*) MAXPT
      MAXPT2=2*MAXPT
      WRITE(*,130)
C
C     Having set up all the run parameters, acquire the data.
      CALL PAUSE(1000)
      CALL ADSWPL(6)
C     This call sets up for real time plotting; the below call
C     erases the screen
      CALL SCERASE
      CALL PAUSE(1000)
C     Open the controller and the acquire the data
      CALL DAOUT(18,ISETFL)
      CALL ADSWST(ICHAN(0),IDELT,IDAT(1),MAXPT2,1)
C
C     Note in the above calls that the analog input channel
C     is 4 and the analog output channel is 18.  These must
C     be changed if a different MFC is used.
C
C     The rest of the program outputs data to a file (if
C     desired) and integrates the curve.
      CALL PAUSE(2000)
      CALL SCERASE
      CALL ADSWPL(0)
      CALL DAOUT(18,-2048)
      WRITE(*,140)
      READ(*,*) IRESP
      IF (IRESP.EQ.1) THEN
         WRITE(*,150)
         OPEN(1,FILE='STORED.OXY',STATUS='NEW')
         WRITE(1,155) RUNNAME,SETFL,IDELT,MAXPT
         WRITE(1,157) BEDP,GNAME,EXHP,TEMP,TIMSET
         WRITE(1,160)
         END IF
      TOTM=0.
      TIME1=0.
      TSEC=FLOAT(IDELT)/1000.
      CALL ADSWGT(IDAT(1),1,1,IFLOW)
      FLOW=FLOAT(IFLOW)*687.76/2047.
      FLOW=FLOW*32./(22400.*60.)
      IF(IRESP.EQ.1) WRITE(1,*) TIME1,FLOW,TOTM
      DO 10 I=2,MAXPT
         TIME1=TIME1 + TSEC
         OLDFL=FLOW
         CALL ADSWGT(IDAT(1),1,I,IFLOW)
         FLOW=FLOAT(IFLOW)*687.76/2047.
C     See the above comment on conversions
         FLOW=FLOW*32./(22400.*60.)
         TOTM=TOTM + ((FLOW + OLDFL)/2.)*TSEC
         IF (IRESP.EQ.1) THEN
            WRITE(1,*) TIME1,FLOW,TOTM
            END IF
10       CONTINUE
      WRITE(*,170) TOTM
      CALL DISI
      STOP
100   FORMAT(///1X,'Venture no further!'/
```

```
     +      5X,'..........the Dark Force awaits to corrupt'/
     +  5X,'           not only your soul, but also your ',
     +      'data!!!!'///
     +      1X,'Enter the name of this run (<8 characters)')
 101  FORMAT(A7)
 102  FORMAT(/1X,'Enter the bed pressure (PSIG)'/
     +      5X,'Enter the bed pressure as a negative number'/
     +      5X,'if the AirCo 0-200 psig gauge is used instead'/
     +      5X,'of the Matheson 0-100 psig gauge')
 103  FORMAT(/1X,'Enter the exhaust pressure (in. Hg ',
     +      'vacuum)')
 104  FORMAT(/1X,'Enter the bed temperature (degrees C)...')
 105  FORMAT(/
     +      1X,'Enter the desired blowdown flowrate (SCCM), ',
     +      'if you dare...')
 106  FORMAT(/1X,'Enter the settling time (minutes)...')
 110  FORMAT(/1X,'Enter the sampling interval (millisec)..')
 120  FORMAT(/1X,'Enter the total # of samples (<2501)...'/
     +      10X,'The experiment will begin with this <CR>!')
 130  FORMAT(///1X,'NOTIFY THE AUTHORITIES!!'//
     +  5X,'The mass flow controller will open 1 second after'/
     +      5X,'               the screen is erased')
 140  FORMAT(1X,'Do you want to save the data?'/
     +      10X,'(1=YES)')
 150  FORMAT(1X,'The data will be stored as ordered triples:'/
     +      5X,'Time (seconds), O2 Flow (gm/sec), Mass Blown (gm)'/
     +  5X,'in file STORED.OXY')
 155  FORMAT(1X,'Data from run ',A7/
     +      5X,'Nominal flow is ',F10.2,1X,'SCCM'/
     +      5X,'The sample time is ',I10,1X,'Milliseconds'/
     +      5X,'The total number of points is ',I5/)
 157  FORMAT(1X,'The bed pressure is ',F6.2,1X,'PSIG'/
     +      5X,'Using the ',A14,1X,'gauge'/
     +      1X,'The exhaust pressure is ',F6.2,1X,'Inches Hg Vacuum'/
     +      1x,'The bed temperature is ',F6.2,1X,'degrees C'/
     +      1X,'The settling time is ',F8.2,1X,'minutes')
 160  FORMAT(1X,'Time (sec), O2 Flow (gm/sec), Mass Blown (gm)')
 170  FORMAT(1X,'The total oxygen mass delivered in this ',
     +      'blowdown:'/5X,E10.4,1X,'grams')
      END
```

APPENDIX C

RAW DATA EXAMPLE--R21O2

Data from run R2102

Nominal flow is 680.00 SCCM

The sample time is 750 Milliseconds

The total number of points is 500

The bed pressure is 50.00 PSIG

Using the AirCo 0-200 gauge

The exhaust pressure is 6.00 Inches Hg Vacuum

The bed temperature is 36.30 degrees C

The settling time is 63.00 minutes

Time (sec), O2 Flow (gm/sec), Mass Blown (gm)

0.000000E+000	1.095949E-002	0.000000E+000
7.500000E-001	1.590326E-002	1.007353E-002
1.5000000	1.606325E-002	2.206097E-002
2.2500000	1.610325E-002	3.412341E-002
3.0000000	1.611925E-002	4.620685E-002
3.7500000	1.612725E-002	5.829929E-002
4.5000000	1.613525E-002	7.039773E-002
5.2500000	1.615125E-002	8.250517E-002
6.0000000	1.615125E-002	9.461860E-002
6.7500000	1.616725E-002	1.067380E-001
7.5000000	1.615125E-002	1.188575E-001
8.2500000	1.616725E-002	1.309769E-001
9.0000000	1.616725E-002	1.431023E-001
9.7500000	1.618325E-002	1.552338E-001
10.5000000	1.617525E-002	1.673682E-001
11.2500000	1.616725E-002	1.794967E-001
12.0000000	1.619125E-002	1.916311E-001
12.7500000	1.618325E-002	2.037715E-001
13.5000000	1.617525E-002	2.159060E-001
14.2500000	1.619125E-002	2.280434E-001
15.0000000	1.619125E-002	2.401868E-001
15.7500000	1.621525E-002	2.523393E-001
16.5000000	1.618325E-002	2.644887E-001
17.2500000	1.619125E-002	2.766291E-001
18.0000000	1.619125E-002	2.887726E-001
18.7500000	1.619125E-002	3.009160E-001
19.5000000	1.618325E-002	3.130564E-001
20.2500000	1.619925E-002	3.251998E-001
21.0000000	1.621525E-002	3.373553E-001
21.7500000	1.618325E-002	3.495047E-001
22.5000000	1.621525E-002	3.616541E-001
23.2500000	1.619125E-002	3.738066E-001
24.0000000	1.621525E-002	3.859590E-001
24.7500000	1.618325E-002	3.981084E-001
25.5000000	1.621525E-002	4.102578E-001
26.2500000	1.619125E-002	4.224103E-001
27.0000000	1.619925E-002	4.345567E-001
27.7500000	1.621525E-002	4.467122E-001
28.5000000	1.619125E-002	4.588646E-001
29.2500000	1.619925E-002	4.710110E-001
30.0000000	1.620725E-002	4.831635E-001
30.7500000	1.620725E-002	4.953189E-001
31.5000000	1.620725E-002	5.074744E-001
32.2500000	1.619925E-002	5.196268E-001
33.0000000	1.619925E-002	5.317762E-001
33.7500000	1.619925E-002	5.439257E-001
34.5000000	1.621525E-002	5.560811E-001
35.2500000	1.621525E-002	5.682425E-001
36.0000000	1.621525E-002	5.804040E-001
36.7500000	1.619925E-002	5.925594E-001
37.5000000	1.621525E-002	6.047148E-001
38.2500000	1.620725E-002	6.168733E-001
39.0000000	1.620725E-002	6.290287E-001

39.7500000	1.619925E-002	6.411811E-001
40.5000000	1.621525E-002	6.533365E-001
41.2500000	1.620725E-002	6.654950E-001
42.0000000	1.619925E-002	6.776474E-001
42.7500000	1.621525E-002	6.898028E-001
43.5000000	1.621525E-002	7.019643E-001
44.2500000	1.619125E-002	7.141167E-001
45.0000000	1.620725E-002	7.262661E-001
45.7500000	1.622324E-002	7.384276E-001
46.5000000	1.620725E-002	7.505890E-001
47.2500000	1.619925E-002	7.627414E-001
48.0000000	1.620725E-002	7.748939E-001
48.7500000	1.621525E-002	7.870523E-001
49.5000000	1.620725E-002	7.992108E-001
50.2500000	1.620725E-002	8.113662E-001
51.0000000	1.620725E-002	8.235216E-001
51.7500000	1.619925E-002	8.356740E-001
52.5000000	1.622324E-002	8.478325E-001
53.2500000	1.619925E-002	8.599910E-001
54.0000000	1.621525E-002	8.721464E-001
54.7500000	1.621525E-002	8.843078E-001
55.5000000	1.620725E-002	8.964663E-001
56.2500000	1.620725E-002	9.086217E-001
57.0000000	1.621525E-002	9.207801E-001
57.7500000	1.621525E-002	9.329416E-001
58.5000000	1.622324E-002	9.451060E-001
59.2500000	1.620725E-002	9.572674E-001
60.0000000	1.621525E-002	9.694259E-001
60.7500000	1.621525E-002	9.815873E-001
61.5000000	1.619925E-002	9.937427E-001
62.2500000	1.621525E-002	1.0058980
63.0000000	1.623124E-002	1.0180660
63.7500000	1.621525E-002	1.0302330
64.5000000	1.620725E-002	1.0423910
65.2500000	1.619925E-002	1.0545440
66.0000000	1.620725E-002	1.0666960
66.7500000	1.620725E-002	1.0788520
67.5000000	1.620725E-002	1.0910070
68.2500000	1.620725E-002	1.1031630
69.0000000	1.622324E-002	1.1153240
69.7500000	1.620725E-002	1.1274860
70.5000000	1.619925E-002	1.1396380
71.2500000	1.621525E-002	1.1517930
72.0000000	1.622324E-002	1.1639580
72.7500000	1.621525E-002	1.1761220
73.5000000	1.621525E-002	1.1882840
74.2500000	1.620725E-002	1.2004420
75.0000000	1.619925E-002	1.2125950
75.7500000	1.620725E-002	1.2247470
76.5000000	1.622324E-002	1.2369090
77.2500000	1.620725E-002	1.2490700
78.0000000	1.621525E-002	1.2612280
78.7500000	1.621525E-002	1.2733900
79.5000000	1.621525E-002	1.2855510
80.2500000	1.623124E-002	1.2977190
81.0000000	1.620725E-002	1.3098830
81.7500000	1.621525E-002	1.3220420
82.5000000	1.620725E-002	1.3342000
83.2500000	1.619925E-002	1.3463530
84.0000000	1.623124E-002	1.3585140
84.7500000	1.621525E-002	1.3706820
85.5000000	1.621525E-002	1.3828430
86.2500000	1.621525E-002	1.3950050
87.0000000	1.621525E-002	1.4071660

87.7500000	1.621525E-002	1.4193270
88.5000000	1.621525E-002	1.4314890
89.2500000	1.621525E-002	1.4436500
90.0000000	1.621525E-002	1.4558120
90.7500000	1.620725E-002	1.4679700
91.5000000	1.620725E-002	1.4801260
92.2500000	1.620725E-002	1.4922810
93.0000000	1.621525E-002	1.5044400
93.7500000	1.621525E-002	1.5166010
94.5000000	1.621525E-002	1.5287630
95.2500000	1.621525E-002	1.5409240
96.0000000	1.621525E-002	1.5530860
96.7500000	1.621525E-002	1.5652470
97.5000000	1.621525E-002	1.5774090
98.2500000	1.621525E-002	1.5895700
99.0000000	1.622324E-002	1.6017350
99.7500000	1.621525E-002	1.6138990
100.5000000	1.621525E-002	1.6260600
101.2500000	1.622324E-002	1.6382250
102.0000000	1.620725E-002	1.6503860
102.7500000	1.621525E-002	1.6625450
103.5000000	1.622324E-002	1.6747030
104.2500000	1.620725E-002	1.6868710
105.0000000	1.621525E-002	1.6990290
105.7500000	1.622324E-002	1.7111940
106.5000000	1.621525E-002	1.7233580
107.2500000	1.620725E-002	1.7355170
108.0000000	1.623124E-002	1.7476810
108.7500000	1.619925E-002	1.7598430
109.5000000	1.620725E-002	1.7719950
110.2500000	1.622324E-002	1.7841560
111.0000000	1.622324E-002	1.7963240
111.7500000	1.621525E-002	1.8084880
112.5000000	1.621525E-002	1.8206500
113.2500000	1.619925E-002	1.8328050
114.0000000	1.621525E-002	1.8449610
114.7500000	1.622324E-002	1.8571250
115.5000000	1.620725E-002	1.8692870
116.2500000	1.620725E-002	1.8814420
117.0000000	1.622324E-002	1.8936040
117.7500000	1.623924E-002	1.9057770
118.5000000	1.621525E-002	1.9179470
119.2500000	1.619925E-002	1.9301030
120.0000000	1.622324E-002	1.9422610
120.7500000	1.621525E-002	1.9544260
121.5000000	1.619125E-002	1.9665780
122.2500000	1.621525E-002	1.9787310
123.0000000	1.621525E-002	1.9908920
123.7500000	1.620725E-002	2.0030510
124.5000000	1.623924E-002	2.0152180
125.2500000	1.620725E-002	2.0273850
126.0000000	1.619925E-002	2.0395380
126.7500000	1.621525E-002	2.0516930
127.5000000	1.622324E-002	2.0638580
128.2500000	1.621525E-002	2.0760220
129.0000000	1.619925E-002	2.0881780
129.7500000	1.621525E-002	2.1003330
130.5000000	1.620725E-002	2.1124920
131.2500000	1.620725E-002	2.1246470
132.0000000	1.621525E-002	2.1368060
132.7500000	1.620725E-002	2.1489640
133.5000000	1.623124E-002	2.1611280
134.2500000	1.621525E-002	2.1732960
135.0000000	1.619925E-002	2.1854510

135.7500000	1.621525E-002	2.1976070
136.5000000	1.620725E-002	2.2097650
137.2500000	1.621525E-002	2.2219240
138.0000000	1.621525E-002	2.2340850
138.7500000	1.621525E-002	2.2462470
139.5000000	1.621525E-002	2.2584080
140.2500000	1.621525E-002	2.2705700
141.0000000	1.623924E-002	2.2827400
141.7500000	1.622324E-002	2.2949140
142.5000000	1.619925E-002	2.3070720
143.2500000	1.620725E-002	2.3192240
144.0000000	1.621525E-002	2.3313830
144.7500000	1.620725E-002	2.3435410
145.5000000	1.623124E-002	2.3557050
146.2500000	1.620725E-002	2.3678700
147.0000000	1.621525E-002	2.3800280
147.7500000	1.620725E-002	2.3921870
148.5000000	1.621525E-002	2.4043450
149.2500000	1.624724E-002	2.4165180
150.0000000	1.621525E-002	2.4286920
150.7500000	1.619925E-002	2.4408470
151.5000000	1.622324E-002	2.4530060
152.2500000	1.621525E-002	2.4651700
153.0000000	1.620725E-002	2.4773290
153.7500000	1.621525E-002	2.4894870
154.5000000	1.620725E-002	2.5016450
155.2500000	1.619925E-002	2.5137980
156.0000000	1.623124E-002	2.5259590
156.7500000	1.620725E-002	2.5381240
157.5000000	1.619925E-002	2.5502760
158.2500000	1.620725E-002	2.5624280
159.0000000	1.622324E-002	2.5745900
159.7500000	1.620725E-002	2.5867510
160.5000000	1.620725E-002	2.5989070
161.2500000	1.622324E-002	2.6110680
162.0000000	1.621525E-002	2.6232330
162.7500000	1.620725E-002	2.6353910
163.5000000	1.619925E-002	2.6475440
164.2500000	1.622324E-002	2.6597020
165.0000000	1.620725E-002	2.6718640
165.7500000	1.623124E-002	2.6840280
166.5000000	1.620725E-002	2.6961920
167.2500000	1.620725E-002	2.7083480
168.0000000	1.622324E-002	2.7205090
168.7500000	1.622324E-002	2.7326770
169.5000000	1.622324E-002	2.7448440
170.2500000	1.622324E-002	2.7570120
171.0000000	1.620725E-002	2.7691730
171.7500000	1.620725E-002	2.7813290
172.5000000	1.621525E-002	2.7934870
173.2500000	1.620725E-002	2.8056450
174.0000000	1.621525E-002	2.8178040
174.7500000	1.621525E-002	2.8299650
175.5000000	1.620725E-002	2.8421240
176.2500000	1.620725E-002	2.8542790
177.0000000	1.620725E-002	2.8664350
177.7500000	1.620725E-002	2.8785900
178.5000000	1.619125E-002	2.8907400
179.2500000	1.621525E-002	2.9028920
180.0000000	1.621525E-002	2.9150540
180.7500000	1.620725E-002	2.9272120
181.5000000	1.621525E-002	2.9393700
182.2500000	1.619925E-002	2.9515260
183.0000000	1.621525E-002	2.9636810

183.7500000	1.620725E-002	2.9758400
184.5000000	1.620725E-002	2.9879950
185.2500000	1.620725E-002	3.0001510
186.0000000	1.619925E-002	3.0123030
186.7500000	1.619925E-002	3.0244530
187.5000000	1.620725E-002	3.0366050
188.2500000	1.619925E-002	3.0487580
189.0000000	1.620725E-002	3.0609100
189.7500000	1.619925E-002	3.0730620
190.5000000	1.619925E-002	3.0852120
191.2500000	1.622324E-002	3.0973700
192.0000000	1.619125E-002	3.1095260
192.7500000	1.622324E-002	3.1216810
193.5000000	1.620725E-002	3.1338430
194.2500000	1.618325E-002	3.1459890
195.0000000	1.623124E-002	3.1581450
195.7500000	1.620725E-002	3.1703090
196.5000000	1.619925E-002	3.1824620
197.2500000	1.620725E-002	3.1946140
198.0000000	1.621525E-002	3.2067720
198.7500000	1.618325E-002	3.2189220
199.5000000	1.620725E-002	3.2310680
200.2500000	1.619125E-002	3.2432170
201.0000000	1.621525E-002	3.2553700
201.7500000	1.619925E-002	3.2675250
202.5000000	1.619125E-002	3.2796720
203.2500000	1.619125E-002	3.2918150
204.0000000	1.622324E-002	3.3039710
204.7500000	1.620725E-002	3.3161320
205.5000000	1.618325E-002	3.3282790
206.2500000	1.620725E-002	3.3404250
207.0000000	1.618325E-002	3.3525720
207.7500000	1.618325E-002	3.3647090
208.5000000	1.618325E-002	3.3768470
209.2500000	1.618325E-002	3.3889840
210.0000000	1.618325E-002	3.4011210
210.7500000	1.619125E-002	3.4132620
211.5000000	1.618325E-002	3.4254020
212.2500000	1.619125E-002	3.4375430
213.0000000	1.618325E-002	3.4496830
213.7500000	1.616725E-002	3.4618150
214.5000000	1.619125E-002	3.4739490
215.2500000	1.618325E-002	3.4860900
216.0000000	1.616725E-002	3.4982210
216.7500000	1.617525E-002	3.5103500
217.5000000	1.618325E-002	3.5224840
218.2500000	1.617525E-002	3.5346190
219.0000000	1.618325E-002	3.5467530
219.7500000	1.616725E-002	3.5588850
220.5000000	1.615125E-002	3.5710040
221.2500000	1.616725E-002	3.5831240
222.0000000	1.617525E-002	3.5952520
222.7500000	1.615925E-002	3.6073780
223.5000000	1.615125E-002	3.6194940
224.2500000	1.615925E-002	3.6316110
225.0000000	1.613525E-002	3.6437210
225.7500000	1.613525E-002	3.6558230
226.5000000	1.614325E-002	3.6679270
227.2500000	1.614325E-002	3.6800340
228.0000000	1.614325E-002	3.6921420
228.7500000	1.612725E-002	3.7042430
229.5000000	1.612725E-002	3.7163390
230.2500000	1.611925E-002	3.7284310
231.0000000	1.611925E-002	3.7405200

231.7500000	1.611125E-002	3.7526070
232.5000000	1.609525E-002	3.7646840
233.2500000	1.609525E-002	3.7767560
234.0000000	1.608725E-002	3.7888240
234.7500000	1.606325E-002	3.8008800
235.5000000	1.605525E-002	3.8129250
236.2500000	1.603925E-002	3.8249600
237.0000000	1.603125E-002	3.8369870
237.7500000	1.602325E-002	3.8490070
238.5000000	1.599126E-002	3.8610120
239.2500000	1.592726E-002	3.8729820
240.0000000	1.592726E-002	3.8849270
240.7500000	1.592726E-002	3.8968730
241.5000000	1.588726E-002	3.9088030
242.2500000	1.582326E-002	3.9206950
243.0000000	1.565527E-002	3.9324990
243.7500000	1.559127E-002	3.9442160
244.5000000	1.588726E-002	3.9560210
245.2500000	1.583126E-002	3.9679150
246.0000000	1.577527E-002	3.9797680
246.7500000	1.560727E-002	3.9915360
247.5000000	1.549528E-002	4.0032000
248.2500000	1.531929E-002	4.0147550
249.0000000	1.508730E-002	4.0261580
249.7500000	1.431933E-002	4.0371850
250.5000000	1.330338E-002	4.0475440
251.2500000	1.234343E-002	4.0571610
252.0000000	1.132747E-002	4.0660380
252.7500000	1.023152E-002	4.0741220
253.5000000	9.335565E-003	4.0814600
254.2500000	8.319613E-003	4.0880810
255.0000000	7.383657E-003	4.0939700
255.7500000	6.623692E-003	4.0992230
256.5000000	5.919725E-003	4.1039270
257.2500000	5.247756E-003	4.1081140
258.0000000	4.591786E-003	4.1118040
258.7500000	3.975815E-003	4.1150170
259.5000000	3.407842E-003	4.1177860
260.2500000	2.887866E-003	4.1201470
261.0000000	2.423887E-003	4.1221390
261.7500000	2.023906E-003	4.1238060
262.5000000	1.687921E-003	4.1251980
263.2500000	1.423934E-003	4.1263650
264.0000000	1.199944E-003	4.1273490
264.7500000	1.015953E-003	4.1281810
265.5000000	7.599647E-004	4.1288470
266.2500000	5.759732E-004	4.1293480
267.0000000	4.319799E-004	4.1297260
267.7500000	3.279847E-004	4.1300110
268.5000000	2.719873E-004	4.1302360
269.2500000	2.239896E-004	4.1304220
270.0000000	1.919911E-004	4.1305780
270.7500000	1.679322E-004	4.130[illegible]130
271.5000000	1.599926E-004	4.1308360
272.2500000	1.439933E-004	4.1309500
273.0000000	1.359937E-004	4.1310550
273.7500000	1.279940E-004	4.1311540
274.5000000	1.199944E-004	4.1312470
275.2500000	1.199944E-004	4.1313370
276.0000000	1.279940E-004	4.1314300
276.7500000	1.199944E-004	4.1315230
277.5000000	1.199944E-004	4.1316130
278.2500000	1.039952E-004	4.1316970
279.0000000	1.119948E-004	4.1317780

279.7500000	9.599554E-005	4.1318560
280.5000000	9.599554E-005	4.1319280
281.2500000	9.599554E-005	4.1320000
282.0000000	9.599554E-005	4.1320720
282.7500000	8.799591E-005	4.1321420
283.5000000	8.799591E-005	4.1322070
284.2500000	7.999628E-005	4.1322700
285.0000000	8.799591E-005	4.1323330
285.7500000	8.799591E-005	4.1323990
286.5000000	7.999628E-005	4.1324620
287.2500000	7.999628E-005	4.1325220
288.0000000	7.199665E-005	4.1325790
288.7500000	7.999628E-005	4.1326370
289.5000000	7.999628E-005	4.1326970
290.2500000	7.199665E-005	4.1327540
291.0000000	5.599740E-005	4.1328020
291.7500000	5.599740E-005	4.1328440
292.5000000	5.599740E-005	4.1328860
293.2500000	5.599740E-005	4.1329280
294.0000000	4.799777E-005	4.1329670
294.7500000	4.799777E-005	4.1330030
295.5000000	4.799777E-005	4.1330390
296.2500000	4.799777E-005	4.1330740
297.0000000	4.799777E-005	4.1331100
297.7500000	4.799777E-005	4.1331460
298.5000000	3.999814E-005	4.1331790
299.2500000	4.799777E-005	4.1332120
300.0000000	3.999814E-005	4.1332450
300.7500000	3.999814E-005	4.1332750
301.5000000	3.199851E-005	4.1333020
302.2500000	3.199851E-005	4.1333260
303.0000000	3.199851E-005	4.1333490
303.7500000	3.999814E-005	4.1333770
304.5000000	3.199851E-005	4.1334040
305.2500000	3.199851E-005	4.1334280
306.0000000	2.399889E-005	4.1334490
306.7500000	2.399889E-005	4.1334670
307.5000000	2.399889E-005	4.1334850
308.2500000	2.399889E-005	4.1335030
309.0000000	3.199851E-005	4.1335240
309.7500000	2.399889E-005	4.1335450
310.5000000	2.399889E-005	4.1335630
311.2500000	2.399889E-005	4.1335810
312.0000000	2.399889E-005	4.1335990
312.7500000	3.199851E-005	4.1336200
313.5000000	1.599926E-005	4.1336380
314.2500000	2.399889E-005	4.1336530
315.0000000	2.399889E-005	4.1336710
315.7500000	1.599926E-005	4.1336860
316.5000000	1.599926E-005	4.1336980
317.2500000	2.399889E-005	4.1337130
318.0000000	0.000000E+000	4.1337220
318.7500000	1.599926E-005	4.1337280
319.5000000	1.599926E-005	4.1337400
320.2500000	7.999628E-006	4.1337490
321.0000000	1.599926E-005	4.1337580
321.7500000	7.999628E-006	4.1337670
322.5000000	7.999628E-006	4.1337730
323.2500000	7.999628E-006	4.1337800
324.0000000	1.599926E-005	4.1337890
324.7500000	1.599926E-005	4.1338010
325.5000000	2.399889E-005	4.1338150
326.2500000	1.599926E-005	4.1338300
327.0000000	1.599926E-005	4.1338420

327.7500000	1.599926E-005	4.1338540
328.5000000	7.999628E-006	4.1338630
329.2500000	7.999628E-006	4.1338690
330.0000000	7.999628E-006	4.1338750
330.7500000	7.999628E-006	4.1338820
331.5000000	7.999628E-006	4.1338880
332.2500000	7.999628E-006	4.1338940
333.0000000	0.000000E+000	4.1338970
333.7500000	0.000000E+000	4.1338970
334.5000000	1.599926E-005	4.1339030
335.2500000	7.999628E-006	4.1339120
336.0000000	7.999628E-006	4.1339180
336.7500000	1.599926E-005	4.1339270
337.5000000	7.999628E-006	4.1339360
338.2500000	7.999628E-006	4.1339430
339.0000000	7.999628E-006	4.1339490
339.7500000	7.999628E-006	4.1339550
340.5000000	1.599926E-005	4.1339640
341.2500000	7.999628E-006	4.1339730
342.0000000	1.599926E-005	4.1339820
342.7500000	7.999628E-006	4.1339910
343.5000000	1.599926E-005	4.1340000
344.2500000	7.999628E-006	4.1340090
345.0000000	7.999628E-006	4.1340160
345.7500000	7.999628E-006	4.1340220
346.5000000	1.599926E-005	4.1340310
347.2500000	1.599926E-005	4.1340430
348.0000000	0.000000E+000	4.1340490

APPENDIX D

TABULATED DATA

	A	B	C	D	E	F	G
1	Grams/lb	453.597		MW oxygen	32		Pressure vs. Alt., Alt =
2	Psia/Atm	14.696		SCCM/gm mol.	22400		a, ft./psia
3	MPa/Atm	0.101325		°C-K	273.16		b, ft.
4	mmHg/Atm	760		R,cc-atm/gmmol-K	82.057		ft./m
5	in. Hg/Atm	29.92		R,atm-cu. ft/lbmol-K	1.314		5A Void Fraction
6	cc/cu. m	1000000		Bed X-section, sq. in.	0.6793		OxySieve-5 Void Frac
7	cc/cu. ft.	28317		Bed X-section, sq. cm.	4.3825		5A Bulk Density (kg/l)
8							
9							
10	Run Number	Date	Lab Book #	Lab Book Pg. #	Valid Run?	Exp. Design Run #	Sample Time (millisec)
11	R1O2	16-Jun-88	1	16	N	0	1000
12	R2O2	17-Jun-88	1	18	N	1	1000
13	R3O2	17-Jun-88	1	19	N	1	1000
14	R4O2	17-Jun-88	1	19	N	1	1000
15	R5O2	17-Jun-88	1	20	N	1	1000
16	R6O2	17-Jun-88	1	20	N	1	1000
17	R7O2	17-Jun-88	1	20	N	1	1000
18	R8O2	17-Jun-88	1	20	Y	1	1000
19	R9O2	17-Jun-88	1	21	N	1	1000
20	R10O2	18-Jun-88	1	21	N	1	1000
21	R11O2	20-Jun-88	1	22	N	2	1000
22	R12O2	20-Jun-88	1	23	N	3	750
23	R13O2	21-Jun-88	1	24	Y	4	1000
24	R14O2	21-Jun-88	1	24	Y	5	1000
25	R15O2	21-Jun-88	1	24	Y	6	500
26	R16O2	21-Jun-88	1	25	Y	7	1000
27	R17O2	22-Jun-88	1	25	Y	8	1000
28	R18O2	22-Jun-88	1	26	Y	8.5	750
29	R19O2	23-Jun-88	1	27	Y	10	1000
30	R20O2	23-Jun-88	1	27	Y	2	1000
31	R21O2	23-Jun-88	1	27	Y	3	750
32	R22O2	26-Jun-88	1	29	N	1	1000
33	R23O2	26-Jun-88	1	30	N	1	1000
34	R24O2	26-Jun-88	1	30	Y	1	1000
35	R25O2	27-Jun-88	1	31	Y	2	1000
36	R26O2	27-Jun-88	1	31	Y	3	500
37	R27O2	27-Jun-88	1	32	Y	4	1000
38	R28O2	27-Jun-88	1	32	Y	5	1000
39	R29O2	27-Jun-88	1	33	Y	6	300
40	R30O2	27-Jun-88	1	33	Y	7	750
41	R31O2	28-Jun-88	1	33	Y	9	750
42	R32O2	28-Jun-88	1	34	Y	8	1000
43	R33O2	28-Jun-88	1	34	Y	10	1000

O2 Storage Data 2

	H	I	J	K	L	M
1	a(P) + b		O-5 Bulk Density (g/cc)	0.711		
2	-3162.92					
3	46482.29					
4	3.2808					
5	0.5					
6	0.535					
7	0.789					
8						
9						
10	Settle Time (min)	Blowdown Rate (SCCM)	BedP Gauge	BedP Read	BedP Corrected	Temperature (°C)
11	800	9.5	Matheson	80.0 psig	80.0 psig	25
12	4	680	Matheson	80.0 psig	80.0 psig	25
13	4	680	Matheson	80.0 psig	80.0 psig	25
14	4	680	Matheson	80.0 psig	80.0 psig	25
15	10	680	Matheson	80.0 psig	80.0 psig	25
16	26	680	Matheson	80.0 psig	80.0 psig	25
17	40	680	Matheson	80.0 psig	80.0 psig	25
18	66	680	Matheson	80.0 psig	80.0 psig	25
19	152	680	Matheson	80.0 psig	80.0 psig	25
20	807	680	Matheson	80.0 psig	80.0 psig	25
21	62	680	AirCo	109.0 psig	110.0 psig	34
22	63	680	AirCo	50.0 psig	50.0 psig	34
23	64	680	AirCo	80.0 psig	80.0 psig	48.1
24	61	680	AirCo	132.0 psig	134.5 psig	48.1
25	60	680	AirCo	20.0 psig	20.0 psig	48.1
26	60	680	AirCo	80.0 psig	80.0 psig	48.1
27	60	680	AirCo	109.0 psig	110.0 psig	51.5
28	60	680	AirCo	50.0 psig	50.0 psig	51.5
29	60	680	AirCo	80.0 psig	80.0 psig	60.5
30	65	680	AirCo	109.0 psig	110.0 psig	36.3
31	63	680	AirCo	50.0 psig	50.0 psig	36.3
32	10	680	AirCo	80.0 psig	80.0 psig	25
33	30	680	AirCo	80.0 psig	80.0 psig	25
34	62	680	AirCo	80.0 psig	80.0 psig	25
35	60	680	AirCo	109.0 psig	110.0 psig	36.5
36	60	680	AirCo	50.0 psig	50.0 psig	36.5
37	60	680	AirCo	80.0 psig	80.0 psig	42.5
38	65	680	AirCo	131.0 psig	133.0 psig	42.5
39	60	680	AirCo	20.0 psig	20.0 psig	42.5
40	60	680	AirCo	80.0 psig	80.0 psig	42.5
41	60	680	AirCo	50.0 psig	50.0 psig	51.2
42	60	680	AirCo	109.0 psig	110.0 psig	51.2
43	60	680	AirCo	80.0 psig	80.0 psig	60.1

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10	ExP, init (in. Hg Vacuum)	ExP, final (in. Hg Vacuum)	ExP, (in. Hg Vacuum)	Total Mass Blown (g)	Zeolite Type
11	0	0	0		5A
12	12	12	12	7.166	5A
13	12	12	12	7.112	5A
14	11.7	12.1	12.1	7.145	5A
15	11.5	12.1	12.1	7.217	5A
16	11.9	12.1	12.1	7.262	5A
17	11.8	12.1	12.1	7.276	5A
18	11.5	12.1	12.1	7.3	5A
19	12	12.1	12.1	7.314	5A
20	12	12.1	12.1	7.33	5A
21	18.4	17.9	17.9	8.523	5A
22	5.8	5.8	5.8	4.102	5A
23	0	0	0	5.238	5A
24	12	12	12	8.553	5A
25	12.3	12	12	1.924	5A
26	24	24.1	24.1	6.075	5A
27	6	6.1	6.1	6.87	5A
28	12.1	12	12	3.651	5A
29	12	12.1	12.1	4.964	5A
30	18	18.1	18.1	8.53	5A
31	6	6	6	4.134	5A
32	12.1	12	12	5.738	OXYSIEVE-5
33	12	12	12	5.765	OXYSIEVE-5
34	11.9	12	12	5.837	OXYSIEVE-5
35	18.1	18	18	6.921	OXYSIEVE-5
36	6.2	6	6	3.234	OXYSIEVE-5
37	0	0	0	4.49	OXYSIEVE-5
38	12.1	12	12	7.463	OXYSIEVE-5
39	12	12	12	1.589	OXYSIEVE-5
40	24	24	24	5.21	OXYSIEVE-5
41	18	18	18	3.128	OXYSIEVE-5
42	6	6	6	5.722	OXYSIEVE-5
43	11.9	12	12	4.139	OXYSIEVE-5

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10	Zeolite Mass (g)	Zeolite Mass (lb)	Dead Volume (cc)	Dead Volume (cu. m.)	Dead Volume (cu. in.)	Dead Volume (cu. ft.)
11	216.5	0.477	29.68	2.968E-05	1.811	1.048E-03
12	216.5	0.477	29.68	2.968E-05	1.811	1.048E-03
13	216.5	0.477	29.68	2.968E-05	1.811	1.048E-03
14	216.5	0.477	29.68	2.968E-05	1.811	1.048E-03
15	216.5	0.477	29.68	2.968E-05	1.811	1.048E-03
16	216.5	0.477	29.68	2.968E-05	1.811	1.048E-03
17	216.5	0.477	29.68	2.968E-05	1.811	1.048E-03
18	216.5	0.477	29.68	2.968E-05	1.811	1.048E-03
19	216.5	0.477	29.68	2.968E-05	1.811	1.048E-03
20	216.5	0.477	29.68	2.968E-05	1.811	1.048E-03
21	216.5	0.477	29.68	2.968E-05	1.811	1.048E-03
22	216.5	0.477	29.68	2.968E-05	1.811	1.048E-03
23	216.5	0.477	29.68	2.968E-05	1.811	1.048E-03
24	216.5	0.477	29.68	2.968E-05	1.811	1.048E-03
25	216.5	0.477	29.68	2.968E-05	1.811	1.048E-03
26	216.5	0.477	29.68	2.968E-05	1.811	1.048E-03
27	216.5	0.477	29.68	2.968E-05	1.811	1.048E-03
28	216.5	0.477	29.68	2.968E-05	1.811	1.048E-03
29	216.5	0.477	29.68	2.968E-05	1.811	1.048E-03
30	216.5	0.477	29.68	2.968E-05	1.811	1.048E-03
31	216.5	0.477	29.68	2.968E-05	1.811	1.048E-03
32	197.3	0.435	29.68	2.968E-05	1.811	1.048E-03
33	197.3	0.435	29.68	2.968E-05	1.811	1.048E-03
34	197.3	0.435	29.68	2.968E-05	1.811	1.048E-03
35	197.3	0.435	29.68	2.968E-05	1.811	1.048E-03
36	197.3	0.435	29.68	2.968E-05	1.811	1.048E-03
37	197.3	0.435	29.68	2.968E-05	1.811	1.048E-03
38	197.3	0.435	29.68	2.968E-05	1.811	1.048E-03
39	197.3	0.435	29.68	2.968E-05	1.811	1.048E-03
40	197.3	0.435	29.68	2.968E-05	1.811	1.048E-03
41	197.3	0.435	29.68	2.968E-05	1.811	1.048E-03
42	197.3	0.435	29.68	2.968E-05	1.811	1.048E-03
43	197.3	0.435	29.68	2.968E-05	1.811	1.048E-03

O2 Storage Data 2

	Y	Z	AA	AB	AC	AD
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10	Blowdown Rate (g/min	Blowdown Rate (lb/hr)	Bed Velocity (cm/sec)	Bed Velocity (m/sec	Bed Velocity (ft/sec)	BedP, C, 1
11	1.36E-01	1.80E-02	0.122	1.225E-03	4.018E-03	94.7 psia
12	9.71E-01	1.28E-01	0.877	8.767E-03	2.876E-02	94.7 psia
13	9.71E-01	1.28E-01	0.877	8.767E-03	2.876E-02	94.7 psia
14	9.71E-01	1.28E-01	0.877	8.767E-03	2.876E-02	94.7 psia
15	9.71E-01	1.28E-01	0.877	8.767E-03	2.876E-02	94.7 psia
16	9.71E-01	1.28E-01	0.877	8.767E-03	2.876E-02	94.7 psia
17	9.71E-01	1.28E-01	0.877	8.767E-03	2.876E-02	94.7 psia
18	9.71E-01	1.28E-01	0.877	8.767E-03	2.876E-02	94.7 psia
19	9.71E-01	1.28E-01	0.877	8.767E-03	2.876E-02	94.7 psia
20	9.71E-01	1.28E-01	0.877	8.767E-03	2.876E-02	94.7 psia
21	9.71E-01	1.28E-01	0.686	6.859E-03	2.250E-02	124.7 psia
22	9.71E-01	1.28E-01	1.322	1.322E-02	4.337E-02	64.7 psia
23	9.71E-01	1.28E-01	0.945	9.446E-03	3.099E-02	94.7 psia
24	9.71E-01	1.28E-01	0.600	5.996E-03	1.967E-02	149.2 psia
25	9.71E-01	1.28E-01	2.578	2.578E-02	8.458E-02	34.7 psia
26	9.71E-01	1.28E-01	0.945	9.446E-03	3.099E-02	94.7 psia
27	9.71E-01	1.28E-01	0.725	7.250E-03	2.378E-02	124.7 psia
28	9.71E-01	1.28E-01	1.397	1.397E-02	4.584E-02	64.7 psia
29	9.71E-01	1.28E-01	0.981	9.811E-03	3.219E-02	94.7 psia
30	9.71E-01	1.28E-01	0.691	6.910E-03	2.267E-02	124.7 psia
31	9.71E-01	1.28E-01	1.332	1.332E-02	4.370E-02	64.7 psia
32	9.71E-01	1.28E-01	0.819	8.193E-03	2.688E-02	94.7 psia
33	9.71E-01	1.28E-01	0.819	8.193E-03	2.688E-02	94.7 psia
34	9.71E-01	1.28E-01	0.819	8.193E-03	2.688E-02	94.7 psia
35	9.71E-01	1.28E-01	0.646	6.462E-03	2.120E-02	124.7 psia
36	9.71E-01	1.28E-01	1.246	1.246E-02	4.086E-02	64.7 psia
37	9.71E-01	1.28E-01	0.867	8.674E-03	2.846E-02	94.7 psia
38	9.71E-01	1.28E-01	0.556	5.562E-03	1.825E-02	147.7 psia
39	9.71E-01	1.28E-01	2.367	2.367E-02	7.767E-02	34.7 psia
40	9.71E-01	1.28E-01	0.867	8.674E-03	2.846E-02	94.7 psia
41	9.71E-01	1.28E-01	1.305	1.305E-02	4.280E-02	64.7 psia
42	9.71E-01	1.28E-01	0.677	6.769E-03	2.221E-02	124.7 psia
43	9.71E-01	1.28E-01	0.916	9.158E-03	3.005E-02	94.7 psia

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10	BedP, C, 2	BedP, C, 3	BedP, C, 4	BedP, C, 5	Temperature (K)	ExP, init, 1	ExP, init, 2	ExP, init, 3
11	192.8 in. Hg	4897 mm Hg	6.44 atm	0.65290 MPa	298.16	29.92 in Hg	760 mm. Hg	14.70 psia
12	192.8 in. Hg	4897 mm. Hg	6.44 atm	0.65290 MPa	298.16	17.92 in. Hg	455 mm. Hg	8.80 psia
13	192.8 in Hg	4897 mm Hg	6.44 atm	0.65290 MPa	298.16	17.92 in. Hg	455 mm. Hg	8.80 psia
14	192.8 in Hg	4897 mm Hg	6.44 atm	0.65290 MPa	298.16	17.82 in Hg	453 mm. Hg	8.75 psia
15	192.8 in. Hg	4897 mm Hg	6.44 atm	0.65290 MPa	298.16	17.82 in. Hg	453 mm. Hg	8.75 psia
16	192.8 in. Hg	4897 mm Hg	6.44 atm	0.65290 MPa	298.16	17.82 in. Hg	453 mm. Hg	8.75 psia
17	192.8 in Hg	4897 mm. Hg	6.44 atm	0.65290 MPa	298.16	17.82 in. Hg	453 mm. Hg	8.75 psia
18	192.8 in Hg	4897 mm Hg	6.44 atm	0.65290 MPa	298.16	17.82 in. Hg	453 mm Hg	8.75 psia
19	192.8 in. Hg	4897 mm Hg	6.44 atm	0.65290 MPa	298.16	17.82 in. Hg	453 mm. Hg	8.75 psia
20	192.8 in Hg	4897 mm. Hg	6.44 atm	0.65290 MPa	298.16	17.82 in. Hg	453 mm. Hg	8.75 psia
21	253.9 in Hg	6449 mm. Hg	8.49 atm	0.85975 MPa	307.16	12.02 in. Hg	305 mm. Hg	5.90 psia
22	131.7 in. Hg	3346 mm. Hg	4.40 atm	0.44606 MPa	307.16	24.12 in Hg	613 mm. Hg	11.85 psia
23	192.8 in. Hg	4897 mm Hg	6.44 atm	0.65290 MPa	321.26	29.92 in. Hg	760 mm. Hg	14.70 psia
24	303.8 in Hg	7716 mm. Hg	10.15 atm	1.02867 MPa	321.26	17.92 in. Hg	455 mm Hg	8.80 psia
25	70.6 in Hg	1794 mm. Hg	2.36 atm	0.23922 MPa	321.26	17.92 in. Hg	455 mm. Hg	8.80 psia
26	192.8 in. Hg	4897 mm Hg	6.44 atm	0.65290 MPa	321.26	5.82 in Hg	148 mm. Hg	2.86 psia
27	253.9 in Hg	6449 mm Hg	8.49 atm	0.85975 MPa	324.66	23.82 in Hg	605 mm. Hg	11.70 psia
28	131.7 in. Hg	3346 mm Hg	4.40 atm	0.44606 MPa	324.66	17.92 in. Hg	455 mm. Hg	8.80 psia
29	192.8 in. Hg	4897 mm Hg	6.44 atm	0.65290 MPa	333.66	17.82 in. Hg	453 mm. Hg	8.75 psia
30	253.9 in. Hg	6449 mm Hg	8.49 atm	0.85975 MPa	309.46	11.82 in. Hg	300 mm. Hg	5.81 psia
31	131.7 in. Hg	3346 mm. Hg	4.40 atm	0.44608 MPa	309.46	23.92 in. Hg	608 mm. Hg	11.75 psia
32	192.8 in. Hg	4897 mm Hg	6.44 atm	0.65290 MPa	298.16	17.92 in. Hg	455 mm Hg	8.80 psia
33	192.8 in Hg	4897 mm Hg	6.44 atm	0.65290 MPa	298.16	17.92 in. Hg	455 mm. Hg	8.80 psia
34	192.8 in Hg	4897 mm. Hg	6.44 atm	0.65290 MPa	298.16	17.92 in Hg	455 mm. Hg	8.80 psia
35	253.9 in Hg	6449 mm Hg	8.49 atm	0.85975 MPa	309.66	11.92 in Hg	303 mm. Hg	5.85 psia
36	131.7 in Hg	3346 mm Hg	4.40 atm	0.44606 MPa	309.66	23.92 [illegible] Hg	608 mm. Hg	11.75 psia
37	192.8 in Hg	4897 mm Hg	6.44 atm	0.65290 MPa	315.66	29.9[illegible] Hg	760 mm. Hg	14.70 psia
38	300.7 in Hg	7638 mm Hg	10.05 atm	1.01832 MPa	315.66	17.92 [illegible] Hg	455 mm Hg	8.80 psia
39	70.6 in Hg	1794 mm. Hg	2.36 atm	0.23922 MPa	315.66	17.92 in Hg	455 mm. Hg	8.80 psia
40	192.8 in Hg	4897 mm Hg	6.44 atm	0.65290 MPa	315.66	5.92 in Hg	150 mm. Hg	2.91 psia
41	131.7 in. Hg	3346 mm. Hg	4.40 atm	0.44606 MPa	324.36	11.92 in Hg	303 mm. Hg	5.85 psia
42	253.9 in Hg	6449 mm. Hg	8.49 atm	0.85975 MPa	324.36	23.92 in Hg	608 mm. Hg	11.75 psia
43	192.8 in Hg	4897 mm. Hg	6.44 atm	0.65290 MPa	333.26	17.92 in Hg	455 mm. Hg	8.80 psia

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10	ExP init, 4	ExP, init, 5	ExP, final, 1	ExP, final, 2	ExP, final, 3	ExP, final, 4	ExP, final, 5	ExP, 1
11	1.000 atm	0.10133 MPa	29.92 in. Hg	760 mm Hg	14.70 psia	1.000 atm	0.10133 MPa	29.92 in. Hg
12	0.599 atm	0.06069 MPa	17.92 in. Hg	455 mm. Hg	8.80 psia	0.599 atm	0.06069 MPa	17.92 in. Hg
13	0.599 atm	0.06069 MPa	17.92 in. Hg	455 mm. Hg	8.80 psia	0.599 atm	0.06069 MPa	17.92 in. Hg
14	0.596 atm	0.06035 MPa	17.82 in. Hg	453 mm Hg	8.75 psia	0.596 atm	0.06035 MPa	17.82 in. Hg
15	0.596 atm	0.06035 MPa	17.82 in. Hg	453 mm. Hg	8.75 psia	0.596 atm	0.06035 MPa	17.82 in. Hg
16	0.596 atm	0.06035 MPa	17.82 in. Hg	453 mm Hg	8.75 psia	0.596 atm	0.06035 MPa	17.82 in Hg
17	0.596 atm	0.06035 MPa	17.82 in. Hg	453 mm Hg	8.75 psia	0.596 atm	0.06035 MPa	17.82 in Hg
18	0.596 atm	0.06035 MPa	17.82 in. Hg	453 mm. Hg	8.75 psia	0.596 atm	0.06035 MPa	17.82 in. Hg
19	0.596 atm	0.06035 MPa	17.82 in. Hg	453 mm. Hg	8.75 psia	0.596 atm	0.06035 MPa	17.82 in Hg
20	0.596 atm	0.06035 MPa	17.82 in. Hg	453 mm. Hg	8.75 psia	0.596 atm	0.06035 MPa	17.82 in. Hg
21	0.402 atm	0.04071 MPa	12.02 in. Hg	305 mm. Hg	5.90 psia	0.402 atm	0.04071 MPa	12.02 in. Hg
22	0.806 atm	0.08168 MPa	24.12 in. Hg	613 mm. Hg	11.85 psia	0.806 atm	0.08168 MPa	24.12 in. Hg
23	1.000 atm	0.10133 MPa	29.92 in. Hg	760 mm. Hg	14.70 psia	1.000 atm	0.10133 MPa	29.92 in. Hg
24	0.599 atm	0.06069 MPa	17.92 in. Hg	455 mm. Hg	8.80 psia	0.599 atm	0.06069 MPa	17.92 in. Hg
25	0.599 atm	0.06069 MPa	17.92 in. Hg	455 mm. Hg	8.80 psia	0.599 atm	0.06069 MPa	17.92 in. Hg
26	0.195 atm	0.01971 MPa	5.82 in Hg	148 mm Hg	2.86 psia	0.195 atm	0.01971 MPa	5.82 in. Hg
27	0.796 atm	0.08067 MPa	23.82 in. Hg	605 mm. Hg	11.70 psia	0.796 atm	0.08067 MPa	23.82 in. Hg
28	0.599 atm	0.06069 MPa	17.92 in Hg	455 mm Hg	8.80 psia	0.599 atm	0.06069 MPa	17.92 in. Hg
29	0.596 atm	0.06035 MPa	17.82 in. Hg	453 mm. Hg	8.75 psia	0.596 atm	0.06035 MPa	17.82 in Hg
30	0.395 atm	0.04003 MPa	11.82 in. Hg	300 mm. Hg	5.81 psia	0.395 atm	0.04003 MPa	11.82 in. Hg
31	0.799 atm	0.08101 MPa	23.92 in. Hg	608 mm. Hg	11.75 psia	0.799 atm	0.08101 MPa	23.92 in. Hg
32	0.599 atm	0.06069 MPa	17.92 in Hg	455 mm. Hg	8.80 psia	0.599 atm	0.06069 MPa	17.92 in. Hg
33	0.599 atm	0.06069 MPa	17.92 in Hg	455 mm. Hg	8.80 psia	0.599 atm	0.06069 MPa	17.92 in Hg
34	0.599 atm	0.06069 MPa	17.92 in Hg	455 mm. Hg	8.80 psia	0.599 atm	0.06069 MPa	17.92 in. Hg
35	0.398 atm	0.04037 MPa	11.92 in. Hg	303 mm. Hg	5.85 psia	0.398 atm	0.04037 MPa	11.92 in Hg
36	0.799 atm	0.08101 MPa	23.92 in. Hg	608 mm. Hg	11.75 psia	0.799 atm	0.08101 MPa	23.92 in. Hg
37	1.000 atm	0.10133 MPa	29.92 in Hg	760 mm. Hg	14.70 psia	1.000 atm	0.10133 MPa	29.92 in Hg
38	0.599 atm	0.06069 MPa	17.92 in. Hg	455 mm Hg	8.80 psia	0.599 atm	0.06069 MPa	17.92 in Hg
39	0.599 atm	0.06069 MPa	17.92 in. Hg	455 mm Hg	8.80 psia	0.599 atm	0.06069 MPa	17.92 in Hg
40	0.198 atm	0.02005 MPa	5.92 in. Hg	150 mm. Hg	2.91 psia	0.198 atm	0.02005 MPa	5.92 in Hg
41	0.398 atm	0.04037 MPa	11.92 in. Hg	303 mm Hg	5.85 psia	0.398 atm	0.04037 MPa	11.92 in Hg
42	0.799 atm	0.08101 MPa	23.92 in. Hg	608 mm Hg	11.75 psia	0.799 atm	0.08101 MPa	23.92 in Hg
43	0.599 atm	0.06069 MPa	17.92 in. Hg	455 mm Hg	8.80 psia	0.599 atm	0.06069 MPa	17.92 in Hg

O2 Storage Data 2

	AU	AV	AW	AX	AY	AZ
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10	ExP, 2	ExP, 3	ExP, 4	ExP, 5	ExP, altitude equiv 1	ExP, alt. equiv 2
11	760 mm Hg	14.70 psia	1.000 atm	0.10133 MPa	0 ft	0.0 m
12	455 mm Hg	8.80 psia	0.599 atm	0.06069 MPa	18643 ft	5682.3 m
13	455 mm Hg	8.80 psia	0.599 atm	0.06069 MPa	18643 ft	5682.3 m
14	453 mm Hg	8.75 psia	0.596 atm	0.06035 MPa	18798 ft	5729.7 m
15	453 mm Hg	8.75 psia	0.596 atm	0.06035 MPa	18798 ft	5729.7 m
16	453 mm Hg	8.75 psia	0.596 atm	0.06035 MPa	18798 ft	5729.7 m
17	453 mm Hg	8.75 psia	0.596 atm	0.06035 MPa	18798 ft	5729.7 m
18	453 mm Hg	8.75 psia	0.596 atm	0.06035 MPa	18798 ft	5729.7 m
19	453 mm Hg	8.75 psia	0.596 atm	0.06035 MPa	18798 ft	5729.7 m
20	453 mm Hg	8.75 psia	0.596 atm	0.06035 MPa	18798 ft	5729.7 m
21	305 mm Hg	5.90 psia	0.402 atm	0.04071 MPa	27809 ft	8476.2 m
22	613 mm Hg	11.85 psia	0.806 atm	0.08168 MPa	9011 ft	2746.5 m
23	760 mm Hg	14.70 psia	1.000 atm	0.10133 MPa	0 ft	0.0 m
24	455 mm Hg	8.80 psia	0.599 atm	0.06069 MPa	18643 ft	5682.3 m
25	455 mm Hg	8.80 psia	0.599 atm	0.06069 MPa	18643 ft	5682.3 m
26	148 mm Hg	2.86 psia	0.195 atm	0.01971 MPa	37441 ft	11412.0 m
27	605 mm Hg	11.70 psia	0.796 atm	0.08067 MPa	9477 ft	2888.5 m
28	455 mm Hg	8.80 psia	0.599 atm	0.06069 MPa	18643 ft	5682.3 m
29	453 mm Hg	8.75 psia	0.596 atm	0.06035 MPa	18798 ft	5729.7 m
30	300 mm Hg	5.81 psia	0.395 atm	0.04003 MPa	28119 ft	8570.9 m
31	608 mm Hg	11.75 psia	0.799 atm	0.08101 MPa	9321 ft	2841.2 m
32	455 mm Hg	8.80 psia	0.599 atm	0.06069 MPa	18643 ft	5682.3 m
33	455 mm Hg	8.80 psia	0.599 atm	0.06069 MPa	18643 ft	5682.3 m
34	455 mm Hg	8.80 psia	0.599 atm	0.06069 MPa	18643 ft	5682.3 m
35	303 mm Hg	5.85 psia	0.398 atm	0.04037 MPa	27964 ft	8523.5 m
36	608 mm Hg	11.75 psia	0.799 atm	0.08101 MPa	9321 ft	2841.2 m
37	760 mm Hg	14.70 psia	1.000 atm	0.10133 MPa	0 ft	0.0 m
38	455 mm Hg	8.80 psia	0.599 atm	0.06069 MPa	18643 ft	5682.3 m
39	455 mm Hg	8.80 psia	0.599 atm	0.06069 MPa	18643 ft	5682.3 m
40	150 mm Hg	2.91 psia	0.198 atm	0.02005 MPa	37285 ft	11364.7 m
41	303 mm Hg	5.85 psia	0.398 atm	0.04037 MPa	27964 ft	8523.5 m
42	608 mm Hg	11.75 psia	0.799 atm	0.08101 MPa	9321 ft	2841.2 m
43	455 mm Hg	8.80 psia	0.599 atm	0.06069 MPa	18643 ft	5682.3 m

	BA	BB	BC	BD
1				
2				
3				
4				
5				
6				
7				
8				
9				
10	O2 Mass from dead volume (g)	Gm O2 Delivered by Bed	Gm moles from bed	Gm O2 from bed/gm zeolite
11	2.501E-01	-2.501E-01	-7.817E-03	-1.155E-03
12	2.501E-01	6.916E+00	2.161E-01	3.194E-02
13	2.501E-01	6.862E+00	2.144E-01	3.169E-02
14	2.501E-01	6.895E+00	2.155E-01	3.185E-02
15	2.501E-01	6.967E+00	2.177E-01	3.218E-02
16	2.501E-01	7.012E+00	2.191E-01	3.239E-02
17	2.501E-01	7.026E+00	2.196E-01	3.245E-02
18	2.501E-01	7.050E+00	2.203E-01	3.256E-02
19	2.501E-01	7.064E+00	2.207E-01	3.263E-02
20	2.501E-01	7.080E+00	2.212E-01	3.270E-02
21	3.197E-01	8.203E+00	2.564E-01	3.789E-02
22	1.659E-01	3.936E+00	1.230E-01	1.818E-02
23	2.322E-01	5.006E+00	1.564E-01	2.312E-02
24	3.658E-01	8.187E+00	2.559E-01	3.782E-02
25	8.506E-02	1.839E+00	5.747E-02	8.494E-03
26	2.322E-01	5.843E+00	1.826E-01	2.699E-02
27	3.025E-01	6.568E+00	2.052E-01	3.033E-02
28	1.569E-01	3.494E+00	1.092E-01	1.614E-02
29	2.235E-01	4.740E+00	1.481E-01	2.190E-02
30	3.174E-01	8.213E+00	2.566E-01	3.793E-02
31	1.647E-01	3.969E+00	1.240E-01	1.833E-02
32	2.501E-01	5.488E+00	1.715E-01	2.781E-02
33	2.501E-01	5.515E+00	1.723E-01	2.795E-02
34	2.501E-01	5.587E+00	1.746E-01	2.832E-02
35	3.172E-01	6.604E+00	2.064E-01	3.347E-02
36	1.645E-01	3.069E+00	9.592E-02	1.556E-02
37	2.363E-01	4.254E+00	1.329E-01	2.156E-02
38	3.685E-01	7.094E+00	2.217E-01	3.596E-02
39	8.657E-02	1.502E+00	4.695E-02	7.615E-03
40	2.363E-01	4.974E+00	1.554E-01	2.521E-02
41	1.571E-01	2.971E+00	9.284E-02	1.506E-02
42	3.028E-01	5.419E+00	1.694E-01	2.747E-02
43	2.238E-01	3.915E+00	1.224E-01	1.984E-02

	BE	BF	BG	BH
1				
2				
3				
4				
5				
6				
7				
8				
9				
10	Gm mol O2 bed/gm zeolite	Gm O2/(gm zeolite-atm)	Gmmol O2/(gm zeolite-atm)	Gm O2 from bed/kg zeolite
11	-3.611E-05	-2.122E-04	-6.633E-06	-1.155
12	9.982E-04	5.465E-03	1.708E-04	31.944
13	9.905E-04	5.423E-03	1.695E-04	31.695
14	9.952E-04	5.446E-03	1.702E-04	31.847
15	1.006E-03	5.503E-03	1.720E-04	32.179
16	1.012E-03	5.538E-03	1.731E-04	32.387
17	1.014E-03	5.549E-03	1.734E-04	32.452
18	1.018E-03	5.568E-03	1.740E-04	32.563
19	1.020E-03	5.579E-03	1.743E-04	32.628
20	1.022E-03	5.592E-03	1.747E-04	32.701
21	1.184E-03	4.687E-03	1.465E-04	37.890
22	5.681E-04	5.056E-03	1.580E-04	18.181
23	7.226E-04	4.247E-03	1.327E-04	23.122
24	1.182E-03	3.958E-03	1.237E-04	37.816
25	2.654E-04	4.821E-03	1.506E-04	8.494
26	8.434E-04	4.319E-03	1.350E-04	26.988
27	9.480E-04	3.945E-03	1.233E-04	30.335
28	5.043E-04	4.243E-03	1.326E-04	16.139
29	6.842E-04	3.744E-03	1.170E-04	21.896
30	1.185E-03	4.689E-03	1.465E-04	37.934
31	5.729E-04	5.089E-03	1.590E-04	18.334
32	8.692E-04	4.759E-03	1.487E-04	27.815
33	8.735E-04	4.782E-03	1.494E-04	27.952
34	8.849E-04	4.845E-03	1.514E-04	28.317
35	1.046E-03	4.139E-03	1.293E-04	33.471
36	4.862E-04	4.318E-03	1.349E-04	15.557
37	6.737E-04	3.961E-03	1.238E-04	21.560
38	1.124E-03	3.805E-03	1.189E-04	35.958
39	2.380E-04	4.322E-03	1.351E-04	7.615
40	7.878E-04	4.036E-03	1.261E-04	25.209
41	4.706E-04	3.761E-03	1.175E-04	15.058
42	8.583E-04	3.574E-03	1.117E-04	27.467
43	6.201E-04	3.395E-03	1.061E-04	19.844

	BI	BJ	BK	BL	BM
1					
2					
3					
4					
5					
6					
7					
8					
9					
10	Gm mol O2 bed/kg zeolite	Gm O2/(kg zeolite-atm)	Gmmol O2/(k(zeolite-atm)	BedP-ExP (atm)	BedP+ExP (atm)
11	-0.036	-0.212	-0.007	5.444	7.444
12	0.998	5.465	0.171	5.845	7.043
13	0.990	5.423	0.169	5.845	7.043
14	0.995	5.446	0.170	5.848	7.039
15	1.006	5.503	0.172	5.848	7.039
16	1.012	5.538	0.173	5.848	7.039
17	1.014	5.549	0.173	5.848	7.039
18	1.018	5.568	0.174	5.848	7.039
19	1.020	5.579	0.174	5.848	7.039
20	1.022	5.592	0.175	5.848	7.039
21	1.184	4.687	0.146	8.083	8.887
22	0.568	5.056	0.158	3.596	5.208
23	0.723	4.247	0.133	5.444	7.444
24	1.182	3.958	0.124	9.553	10.751
25	0.265	4.821	0.151	1.762	2.960
26	0.843	4.319	0.135	6.249	6.638
27	0.948	3.945	0.123	7.689	9.281
28	0.504	4.243	0.133	3.803	5.001
29	0.684	3.744	0.117	5.848	7.039
30	1.185	4.689	0.147	8.090	8.880
31	0.573	5.089	0.159	3.603	5.202
32	0.869	4.759	0.149	5.845	7.043
33	0.873	4.782	0.149	5.845	7.043
34	0.885	4.845	0.151	5.845	7.043
35	1.046	4.139	0.129	8.087	8.883
36	0.486	4.318	0.135	3.603	5.202
37	0.674	3.961	0.124	5.444	7.444
38	1.124	3.805	0.119	9.451	10.649
39	0.238	4.322	0.135	1.762	2.960
40	0.788	4.036	0.126	6.246	6.642
41	0.471	3.761	0.118	4.004	4.801
42	0.858	3.574	0.112	7.686	9.284
43	0.620	3.395	0.106	5.845	7.043

	BN
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	Gm Desorbed from Bed/kg zeolite
11	-5.667
12	27.100
13	26.850
14	27.000
15	27.332
16	27.540
17	27.605
18	27.716
19	27.780
20	27.854
21	31.387
22	15.287
23	18.934
24	30.467
25	7.139
26	22.181
27	24.482
28	13.244
29	17.564
30	31.473
31	15.457
32	22.063
33	22.199
34	22.564
35	25.808
36	12.143
37	16.499
38	27.172
39	5.977
40	19.403
41	11.436
42	20.514
43	14.698

APPENDIX E

LANGMUIR CALCULATION TABLES

5A DELH= -3370.0000cal/gm-mol

K is in atm^(-1) and NS is in gm O2/kg zeolite

RUN#	K1	NS1	K2	NS2
R8O2 ,R13O2	-.78556E-02	-10.91	0.21876E-03	107.94
R8O2 ,R14O2	-.16945E-03	-62.29	0.75511E-03	58.69
R8O2 ,R15O2	-.52329E-02	2.16	0.20682E-03	112.11
R8O2 ,R16O2	-.23693E-02	13.85	0.19169E-03	118.16
R8O2 ,R17O2	-.30191E-02	11.82	0.25889E-03	96.78
R8O2 ,R18O2	-.45077E-02	5.57	0.16373E-03	132.31
R8O2 ,R19O2	-.36751E-02	9.24	0.19973E-03	114.83
R8O2 ,R20O2	-.10326E-03	-122.67	0.62631E-03	62.37
R8O2 ,R21O2	-.64573E-02	-3.84	0.16149E-03	133.66
R13O2,R14O2	0.17866E-03	125.96	0.13985E-01	88.68
R13O2,R15O2	-.44464E-02	2.35	0.20064E-03	115.18
R13O2,R16O2	-.79131E-03	0.00	0.13013E-03	162.77
R13O2,R17O2	0.16731E-03	132.64	0.88361E-02	66.77
R13O2,R18O2	-.32645E-02	6.10	0.11696E-03	178.06
R13O2,R19O2	-.20442E-02	8.23	0.17339E-03	128.95
R13O2,R20O2	0.18252E-03	123.88	0.66316E-02	57.74
R13O2,R21O2	-.46479E-02	1.64	0.41228E-04	456.30
R14O2,R15O2	-.85076E-02	0.00	0.19295E-03	119.27
R14O2,R16O2	-.38237E-02	15.49	0.16452E-03	133.73
R14O2,R17O2	0.25175E-01	130.74	0.18719E-03	121.85
R14O2,R18O2	-.81772E-02	1.18	0.14606E-03	146.14
R14O2,R19O2	-.69320E-02	5.56	0.17651E-03	127.06
R14O2,R20O2	0.00000E+00	0.00	0.00000E+00	0.00
R14O2,R21O2	-.65111E-01	-213.76	0.13583E-03	154.49
R15O2,R16O2	0.22213E-03	105.24	0.46201E-01	64.39
R15O2,R17O2	0.19439E-03	118.48	-.63141E-02	1.62
R15O2,R18O2	0.33682E-03	73.71	-.96772E-02	-1.02
R15O2,R19O2	0.21705E-03	107.41	-.12653E-01	-3.87
R15O2,R20O2	0.19430E-03	118.53	-.11443E-01	-2.68
R15O2,R21O2	0.25306E-03	93.91	-.43865E-02	2.35
R16O2,R17O2	0.14929E-03	144.93	-.20681E-02	13.00
R16O2,R18O2	0.72986E-02	32.43	0.10989E-03	188.38
R16O2,R19O2	0.22082E-02	33.70	0.24673E-03	97.14
R16O2,R20O2	0.16724E-03	131.94	-.50384E-02	15.56
R16O2,R21O2	0.58754E-03	54.89	-.13258E-03	-113.07
R17O2,R18O2	-.54333E-02	4.70	0.13099E-03	160.90
R17O2,R19O2	-.41108E-02	8.97	0.17105E-03	130.42
R17O2,R20O2	0.19395E-03	118.68	0.55918E-02	54.94
R17O2,R21O2	-.19584E-01	-49.52	0.10298E-03	196.38
R18O2,R19O2	0.34478E-04	561.75	-.24039E-01	-24.35
R18O2,R20O2	0.14793E-03	144.52	-.12175E-01	-4.88
R18O2,R21O2	0.16844E-03	129.11	-.27244E-02	5.88
R19O2,R20O2	0.17880E-03	125.71	-.10739E-01	-0.57
R19O2,R21O2	0.40049E-03	68.43	-.10644E-02	1.66
R20O2,R21O2	0.24694E-01	112.47	0.13859E-03	151.88

Oxy-5 DELH= -3140.0000cal/gm-mol

K is in atm^(-1) and NS is in gm O2/kg zeolite

RUN#	K1	NS1	K2	NS2
R24O2,R25O2	-.97745E-04	-170.24	0.10583E-02	48.56
R24O2,R26O2	-.94709E-02	-3.12	0.12397E-03	182.99
R24O2,R27O2	-.67842E-01	-175.61	0.22092E-03	115.07
R24O2,R28O2	0.53295E-05	3642.77	0.85476E-02	54.96
R24O2,R29O2	-.77543E-02	1.56	0.19582E-03	126.18
R24O2,R30O2	-.29558E-02	11.85	0.21656E-03	116.82
R24O2,R31O2	-.59689E-02	6.14	0.18714E-03	130.72
R24O2,R32O2	-.43145E-02	9.84	0.43750E-03	72.54
R24O2,R33O2	-.53293E-02	7.66	0.26704E-03	100.14
R25O2,R26O2	0.61120E-01	137.17	0.10072E-03	221.08
R25O2,R27O2	0.49120E-02	41.02	0.16063E-03	149.37
R25O2,R28O2	0.61943E-04	341.56	-.28610E-02	16.49
R25O2,R29O2	-.17471E-01	-3.77	0.17944E-03	136.75
R25O2,R30O2	-.66979E-02	13.56	0.17745E-03	137.96
R25O2,R31O2	-.13224E-01	3.41	0.16717E-03	144.66
R25O2,R32O2	0.57509E-02	41.93	0.30905E-03	91.65
R25O2,R33O2	-.16294E-01	-1.77	0.23522E-03	111.22
R26O2,R27O2	0.36985E-04	571.41	-.52498E-02	3.38
R26O2,R28O2	0.93686E-04	236.34	-.20781E-01	-24.02
R26O2,R29O2	-.63477E-02	1.91	0.28455E-03	90.07
R26O2,R30O2	-.98674E-04	-190.23	0.23771E-02	30.79
R26O2,R31O2	-.32715E-02	4.89	0.32754E-03	80.71
R26O2,R32O2	0.56678E-05	3631.33	-.17590E-01	-17.97
R26O2,R33O2	-.12137E-02	-1.71	0.14251E-02	34.69
R27O2,R28O2	0.13031E-03	178.68	0.24114E-01	93.73
R27O2,R29O2	-.58774E-02	1.97	0.18707E-03	131.60
R27O2,R30O2	-.10392E-02	0.00	0.20959E-03	120.00
R27O2,R31O2	-.40822E-02	5.68	0.17085E-03	141.84
R27O2,R32O2	-.64793E-04	-290.86	0.40848E-02	39.44
R27O2,R33O2	-.29927E-02	7.05	0.30359E-03	90.30
R28O2,R29O2	-.11180E-01	0.00	0.16582E-03	147.14
R28O2,R30O2	-.51603E-02	13.55	0.15076E-03	158.70
R28O2,R31O2	-.89096E-02	5.43	0.15246E-03	157.28
R28O2,R32O2	-.26699E-01	-39.11	0.20246E-03	126.22
R28O2,R33O2	-.89720E-02	5.28	0.20318E-03	125.89
R29O2,R30O2	0.18098E-03	135.68	0.84657E-01	70.95
R29O2,R31O2	0.23004E-03	108.95	0.58737E-01	52.50
R29O2,R32O2	0.15162E-03	159.96	-.90971E-02	1.03
R29O2,R33O2	0.10119E-03	234.58	-.19454E-01	-5.06
R30O2,R31O2	0.11041E+00	86.13	0.15506E-03	154.88
R30O2,R32O2	0.83807E-04	268.89	-.24246E-02	10.62
R30O2,R33O2	0.51888E-02	27.71	0.41887E-03	70.54
R31O2,R32O2	0.12685E-03	186.22	-.66001E-02	6.08
R31O2,R33O2	-.15288E-04	-1417.00	-.87046E-02	5.50
R32O2,R33O2	-.58540E-02	7.45	0.20375E-03	125.59

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